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Impact of the use of treated wastewater for irrigation on the physico-chemical quality of soils: A case study from Ain Defla, Algeria

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Abstract

The use of treated wastewater is considered a good alternative for the different agricultural irrigation practices and the sustainable management program for the conservation of water and soil in semi-arid areas. The main objective of this research work is to determine the impacts of the reuse of treated wastewater (TWW) on some soil properties with the collection and analysis of 68 samples from the Ain Defla wastewater treatment plant (WWTP) over a three-year period, under a turf cultivation system. Soil samples were taken at depths ranging from 0 to 20 and 20 to 40 cm and then analyzed for pH, electrical conductivity (EC) and overall mineralization. The results showed large changes, over time, in the chemical properties of the soil due to irrigation with treated wastewater compared to the control, with median pH values varying from 8.12 in 2015 to 8.15 in 2016 and 8.91 in 2017. The pH increased significantly from 8.12 in non-irrigated soil to 8.22 in soil irrigated with treated wastewater. There was a significant difference between the two horizons (8.15 at the surface and 8.24 at depth). The electrical conductivity went from 0.25 µS/cm in 2015 to 0.37 µS/cm in 2016 to drop to 0.15 µS/cm and 2017. The electrical conductivity has doubled between the non-irrigated soil (0.14 µS/cm) and the irrigated one (0.28 µS/cm) while it has not changed between the two horizons (0.27 µS/cm on the surface and 0.24 µS/cm in depth). The results obtained during these three years show that treated wastewater is a main source of increase in mineral salts in the soil which could lead to the degradation of the environment in general and that of the physico-chemical

quality of soil in a particular. Also, it was found that treated wastewater can be a potential source of essential nutrients for plants by accumulation in soils.

Keywords: Irrigation, Physico-chemical, Reuse, Soil, Treated wastewater.

Introduction

The rate of population growth in semi-arid regions is characterized by high consumption of water resources, in a global context marked by climate change and scarcity of rainfall in recent years. Algeria is one of the Mediterranean countries affected by water stress. It is classified in the category of poor countries in this matter. The TWW in agriculture is proving to be one of the solutions likely to solve, even if only partially, the problem of lack of irrigation water in areas marked with low precipitation (Faby and Brissaud, 1997; Eccose, 2001). Among the wastewater treatment plants operated by the National Sanitation Office (ONA) across the 43 wilayas, there are just a few plants that are concerned with the reuse of TWW in agriculture. In 2011, the volume reused is estimated at 17 million m^3/year, in order to irrigate more than 10,000 hectares of agricultural area MRE (2012). Indeed, this potential for re-using TWW for agricultural purposes has undergone significant development, where approximately 17 million m^3 were recorded in 2011, approximately 45 million m^3 in 2012 and 300 million m^3 in 2014 (MRE, 2012; ONA, 2014). Irrigation with TWW can affect the physicochemical properties of soils (Lado and Ben-Hur, 2009; Levy, 2011; Levy et al., 2011; Feigin et al., 2012; Chen et al., 2004; Tarchouna et al., 2010), and agricultural production Yadav et al. (2002). These impacts depend not only on the quality of the irrigation water but also on the frequency of use of the TWW used, the duration of the irrigation and the local climate (season). The study that we present is a contribution to the evaluation of the impact of the short, medium and long terms of irrigation with treated wastewater from the WWTP at the level of the irrigated perimeter of Ain Defla region characterized by well-defined climatic conditions. The objective of our study is to characterize in more detail the state of the soils after three years of irrigation by TWW and to assess the impact of these waters on the physicochemical properties of the soil such as sodicity and alkalinity at two different depths.

Materials and Methods

The study site is located in the WWTP, located in the town of Ain Defla, 5 km northeast of the capital of the wilaya. The low load activated sludge plant has an area of 5 hectares and a treatment capacity of 12,900 m^3/day. The climate of the region is Mediterranean with an average annual rainfall of 420 mm and the average air temperature is 20 °C.

The study was carried out between September 2015 and September 2017 during three years (2015, 2016, and 2017) on a field covered by grass. During each year, we followed the samples and analyzes of the soil from the point of view of physicochemical parameters (quality and quantity).

To assess the impacts of TWW on the physico-chemical properties of the soil, we chose two plots: a plot not irrigated by TWW but having precipitation water as an irrigation source and a plot irrigated with TWW. No fertilizer was applied in the two plots.

Water sampling and analysis

The water samples were taken directly at the exit of the station after the treatments carried out by the WWTP. These collected waters were sampled in tightly closed plastic bottles, named by codes and kept in a cooler until the time of analysis. The physicochemical analyzes were carried out at the level of the laboratories of the WWTP, the Algerienne des Eaux (ADE), the National Observatory of the Environment and Sustainable Development (ONEDD) of Ain Defla and the Laboratory of Agricultural Production and Sustainable Valuation of Natural Resources (PRAVDURN) of the University of Khemis Miliana.

The irrigation water was analyzed monthly for the parameters pH, electrical conductivity (EC), suspended solids (SS), biological oxygen demand (BOD_5), chemical oxygen demand (COD), total nitrogen (N_t), nitrate (NO_3^-), nitrite (NO_2^-), and total phosphorus (P_t) and once a year for trace elements and major elements such as Cr, Zn, Ni, Pb, Mg, K, Ca, Cl, and Na. The analyzes were carried out according to the standards recommended by ISO and AFNOR or those approved Rodier (1996). The sodium adsorption rate (SAR) and the exchangeable sodium rate (ESP) were calculated using the following standard equations:

$$SAR = Na^{+} / [(Ca^{+2} + Mg^{+2}) / 2] ½ \quad (1)$$

$$ESP = [Na^{+} / [(Ca^{+2} + Mg^{+2} + Na^{+} + K^{+})] * 100 \quad (2)$$

Irrigation protocol

Irrigation was carried out using a gravity-fed irrigation system, the plot irrigated by TWW was more than 20 m from the non-irrigated one to avoid any contamination. The volume of irrigation water and the frequency of application are two critical factors in controlling the impact of TWW on soil properties. Their irrigation is carried out by the same irrigation system during the three years with a constant flow of 1,800 l/h, or a total of 43,200 liters of water per day. The plot is irrigated three times a week during summer and once during spring and autumn.

Soil sampling and analysis

The soil samples were taken in accordance with internationally recommended procedures (*AFNOR NF x31-100*) in September 2015 and 2016, after the summer season and in March 2017 after the winter season. Structural stability analyzes were performed in September 2017. Soil samples were taken from the field using an agricultural auger in two different horizons (0-20 and 20-40 cm) 30 samples for the plot irrigated by TWW and 4 samples for the plot not irrigated. The soil samples were stored in poly bags and marked with sampling details and transferred to the laboratory for testing. The soil was air dried for a week and then sieved. The physical analysis of the soil, to determine the textural classes of the soil using the “Robinson's pipette”

method, complies with standards (*NEN5357 and ISO/DIS 11277*). The structural stability was determined by slow wetting method Bissonnais, Souder (1995). Acidity and salinity of the soil were evaluated by determining the pH and EC at 25 °C on a soil extract (1/2.5 and 1/5 Soil/Water) using a pH meter and a conductivity meter (WTW multi 340i). Organic matter (OM) was determined by the weight loss method using an oven at 375 ºC for 16 hours Moreno et al. (2001). Sodium (Na) and potassium (K) were determined on soil extract using an IC9200 flame photometer (JENWAY PFP7). Chloride (Cl) was determined by the titrimetric method with silver nitrate solution Karaivazoglou et al. (2005). Calcium (Ca) and magnesium (Mg) in soil extracts were determined by the EDTA method Pauwels et al. (1992). Phosphorus (P) was determined using a spectrophotometer (860 nm) by the Olsen method Nelson, Sommers (1982). Total nitrogen was determined by dry combustion (*Elemental analysis / FN ISO; 13878*). The sodium adsorption rate (SAR) Richards (1954) and the exchangeable sodium percentage (ESP) were expressed in cmol/kg and calculated using formulas (1) and (2).

Statistical analyses

Analysis of variance (ANOVA) would be used to test the effects of the three factors (years, irrigation, and depths) on soil properties if data followed normal distribution and had constant variances. However, Shapiro-Wilk test showed the lack of normality of data while the Levene test showed their heteroscedasticity. Therefore, nonparametric methods were used instead. Mann-Whitney test was used to evaluate the effect of the two levels factors (irrigation and depths) while the Kruskal-Wallis test was used to evaluate the effect of the three level factor (years). For the latter, in cases of significant differences, pairwise comparisons were done using the Dunn-Bonferroniposthoc test. Median values should be reported instead of mean values which are given just for comparison.

Results and Discussion

Physicochemical properties of TWW

The physicochemical characteristics of irrigation water (TWW) were monitored during the three years (2015, 2016, and 2017) while heavy metals were only monitored during 2015. Table 1, summarizes the results obtained during these years by indicating the limit values of the monitoring parameters with a comparison with the standards for the reuse of treated wastewater according to the FAO (1985), the Algerian Executive Decree (2012) and the tolerant concentration limits by the European Commission for water irrigation systems (*Catchment Management Agencies, recommendation 91-692 (CMA)*).

Table 1. *Results of physicochimical and heavy metals analyses of TWW (2015-2017).*

Parameter	Unit	2015		2016		2017		Norms	
		F	Mean	F	Mean	F	Mean	JORA 2012	OMS/FAO/CMA
T	°C	12	21.35	12	20.80	12	20.79	<30	-
pH	/	12	7.72	12	7.64	12	7.86	6.5-8.5*	6.5-8.5**
EC	µS/cm	12	1.97	12	1.86	12	1.87	<3*	3**
SAR	/	1	2.18	1	3.74	1	2.31		6-12***
HCO_3^-	mg/l	1	294.3	1	346.2	1	305	-	8.5 meq/l
SO_4^{2-}	mg/l	1	225.6	1	281.3	1	243	-	250***
N total	mg/l	12	7.9	12	6.34	12	8.36	50*	30**
$N\text{-}NO_3^-$	mg/l	12	6.85	12	4.37	12	6.95	30*	5**
$N\text{-}NO_2^-$	mg/l	12	0.13	12	0.07	12	0.15	-	1**
$N\text{-}NH_4^+$	mg/l	12	0.84	12	3.05	12	2.02	5***	2**
P total	mg/l	12	2.6	12	3.24	12	2.26	-	-
$P\text{-}PO_4^{3-}$	mg/l	12	4.27	12	7.04	12	7	5***	0,94*
K	mg/l	1	10.5	1	14.5	1	9.8	-	12***
Na	mg/l	1	115.4	1	221.3	1	123	-	150***
Ca	mg/l	1	148	1	189.5	1	156	-	50***
Mg	mg/l	1	38.88	1	45.6	1	34.06	-	50***
Cl	mg/l	1	289.4	1	281.3	1	300.68	10 meq/l	200***
SS	mg/l	12	20.44	12	75.25	12	16.92	30*	30**
DBO	mg/l	12	6.7	12	12.71	12	8.87	30	10**
DCO	mg/l	12	30.55	12	32.76	12	29.27	90	40**
Pb	mg/l	1	<0.2	-	-	-	-	-	5**
Ni	mg/l	1	<0.2	-	-	-	-	-	0,2**
Fe	mg/l	1	<0.2	-	-	-	-	-	5**
Cu	mg/l	1	<0.1	-	-	-	-	-	0,2**
Zn	mg/l	1	<0.03	-	-	-	-	-	2**
Cr	mg/l	1	<0.2	-	-	-	-	-	0,1**

*** CMA 91-692. ** FAO (1985). * OMS (1989).

F: frequency of analyzes; EC: electrical conductivity; SS: suspended solids; COD: chemical oxygen demand; BOD: biochemical oxygen demand; SAR: sodium adsorption rate. T: temperature.

The average pH of TWW, for the three years, is within the standards, between 6.5 and 8.5 JORA (2012), and is acceptable because it is in the range based on FAO standards (Ayers and Westcot, 1985; Pescod, 1992). The EC ranges from 1.87 to 1.97 µS/cm, indicating a light to moderate level of salinity Pescod (1992). These values remain below the limit value of 3 µS/cm for use in irrigation JORA (2012) and there is no risk for the physical properties of the soil Ayers, Westcot (1985). The concentration of Cl varies between 281.3 and 300.68 mg/l, this is an acceptable concentration for surface irrigation (Boulahbal, 2011; Ayers and Westcot, 1985).

The COD and BOD_5 are in the Algerian standards for the reuse of TWW in irrigation JORA (2012). The high level of SS for 2016 is due to the loss of sludge from the clarifier, this value remains above the acceptable range based on the standards (JORA, 2012; Ayers and Westcot, 1985). In general, the contents of Ca, K, Na, Mg, and NH4 are variable over the years but we can indicate that, according to the standards, SO_4^{2-}, NO_3^-, NO_2^-, HCO_3^-, and P show no change in the nature of the

irrigation water. In addition, the concentration of heavy metals is low and lower than the standard for irrigation water (JORA, 2012; Ayers and Westcot, 1985), the element most represented is chromium with a content of less than 0.2 mg/l. These concentrations will have no toxic effect on soil characteristics Godfrin, Van Bladel (1990).

Effects of TWW on soil properties

Soil texture

Textural analysis shows that the two irrigated plots have high sand contents compared to the other two fractions (Table 2).

Table 2. *Physical properties of the soil (Soil texture) in the experimental site.*

Plot	Depth	Sand (%)	Silt (%)	Clay (%)	Texture
Irrigated	0-20 cm	61.5	11.5	27.0	Sandy clay loam
	20-40 cm	47.5	20.8	31.7	Sandy clay loam
Non irrigated	0-20 cm	54.0	16.0	30.0	Sandy clay loam
	20-40 cm	55.5	13.5	31.0	Sandy clay loam

Soil pH

The results of the effects of years, depths, and irrigations with TWW on the chemical properties of the soil are shown in Tables 3 to 5. Since the distributions of these properties are not normal, the results will be discussed based on median values which are robust to extreme values instead of mean values which are too sensitive to them and hypothesis testing relying on non-parametric methods.

The median pH values of soils irrigated by TWW vary from 8.12 (2005) to 8.91 (2007) (Table 3), these values classify the soils between moderately and strongly alkaline according to the American classification USDA Staff (1993). This could be mainly due to higher concentrations, over time, of cations in wastewater used in basic irrigation which led to an increase in soil pH Gharaibeh et al. (2016). This indicates that three years of TWW irrigation led to a significant increase in pH between years (Table 3), between horizons (median values of 8.15 and 8.24 for surface and in depth) (Table 4) and between irrigation water types with a median of 8.22 in the irrigated plot and 8.12 in the control plot (Table 5). This result is similar to other studies (Mancino and Pepper, 1992; Tarchouna et al., 2010; Cromer et al., 1984) which reported that irrigation with TWW increased pH due to the textural nature of the soil which is a fundamental factor to determine the acidity of the soil, which allows the salts to be leached in depth. The use of TWW in irrigation can have negative effects on the chemical quality of the soil (Kiziloglu et al., 2007; Mutengu et al., 2007).

Table 3. *Results for years. NS: not significant at the 0.05 level. Years with different letters are significantly different following the Dunn-Bonferroni post-hoc test.*

Soil property / Year	Mean			Median			Significance
	2015	2016	2017	2015	2016	2017	
P	17.05	19.46	10.00	12.84 a	18.79 a	9.00 b	0
Mg	20.07	21.37	20.05	20.30 b	22.30 a	20.16 b	0.039
Na	1.95	2.18	2.45	1.98 a	2.03 a	2.33 b	0.008
K	8.76	9.57	12.77	8.68 c	9.49 b	12.45 a	0
Nt	3.11	0.77	0.08	1.46 a	0.69 a	0.08 b	0
Ca	249.43	254.32	247.79	248.40 b	252.45 a	248.58 b	0
Cl	34.51	84.88	81.23	26.98 b	88.7 a	80.81 a	0
pH	8.09	8.15	8.92	8.12 b	8.15 b	8.91 a	0
EC	0.25	0.37	0.15	0.24 b	0.40 a	0.13 c	0
OM	1.29	1.40	1.38	1.07	1.22	1.41	NS
SAR	0.17	0.19	0.20	0.17 b	0.18 b	0.19 a	0
ESP	0.69	0.76	0.84	0.70 b	0.72 b	0.77 a	0

Table 4. *Results for depths. NS: not significant at the 0.05 level.*

Soil property / Depth	Mean		Median		Significance
	0-20 cm	20-40 cm	0-20 cm	20-40 cm	
P	14.67	16.57	12.00	13.31	NS
Mg	21.41	19.52	22.20	20.09	0.001
Na	2.10	2.27	2.03	2.07	NS
K	10.11	10.43	9.47	9.46	NS
Nt	0.55	1.93	0.19	0.29	NS
Ca	248.27	252.90	248.40	251.35	NS
Cl	84.76	51.02	83.20	48.28	0
pH	8.29	8.37	8.15	8.24	0.01
EC	0.26	0.27	0.27	0.24	NS
OM	1.39	1.33	1.25	1.10	NS
SAR	0.18	0.19	0.18	0.17	0
ESP	0.76	0.78	0.73	0.70	0

Table 5. *Results for irrigation. NS: not significant at the 0.05 level.*

Soil property / Treatment	Mean		Median		Significance
	EUT	NI	EUT	NI	
P	17.07	6.42	13.60	7.70	0
Mg	21.36	14.42	21.22	14.73	0
Na	2.26	1.62	2.08	1.60	0
K	10.34	9.77	9.54	8.91	NS
N_t	1.42	0.10	0.54	0.10	0.005
Ca	250.96	246.60	251.10	245.85	0.002
Cl	71.48	44.11	62.50	27.00	0
pH	8.35	8.17	8.22	8.12	0.018
EC	0.28	0.14	0.28	0.14	0
OM	1.42	0.89	1.26	0.95	0
SAR	0.19	0.14	0.18	0.15	NS
ESP	0.80	0.61	0.75	0.61	NS

Soil salinity

There is a significant difference between the years concerning the EC of the TWW irrigated soil solution with the highest median value in 2016 (0.40 µS/cm) and the lowest in 2017 (0.13 µS/cm) (Table 3). The decrease in EC in 2017 may be explained by climatic conditions such as seasonal fall and winter precipitation which was sufficient to ensure dilution and migration to depth of salts accumulated during the summer season Melgar et al., (2009). There is no significant difference between the two horizons (0.27 and 0.24 µS/cm) (Table 4). In addition, there is a significant difference between irrigation with TWW and non-irrigation because irrigation doubled the median value of EC (0.28 µS/cm vs. 0.14 µS/cm) (Table 5). Similar results have been reported (Jahantigh, 2008; Gil and Ulloa, 1997; Galavi et al., 2010; Khai et al., 2016; Massena, 2001; Xanthoulis et al., 1998). In all cases, the values obtained allow us to consider the soils as unsalted according to the recommended limits Mathieu et al. (2003), and they are below the salinity threshold of 4 µS/cm. However, irrigation with TWW could, over time, cause salinization problems linked to the degradation of the physico-chemical properties of the soil.

Organic matter

The median values of OM, although they increase with the years, do not differ significantly (Table 3) with a little more in surface compared to in depth with the difference not being significant (Table 4). On the other hand, there is a significant difference between the irrigated plot (1.26%) and the control one (0.95%) (Table 5). Similar results were found for years (Kiziloglu et al., 2007; Manas et al., 2009) but different for depths (Bedbabis et al., 2014, 2015; Jueschke et al., 2008; Tarchouna et al., 2010). The decrease in OM values measured in the surface layer in 2017 is probably the consequence of low volume of suspended solids. Some studies have shown that the increase in OM was temporary because it is rapidly mineralized by soil microorganisms (Mechri et al., 2007; Di Serio et al., 2008).

Ionic composition of the soil solution

The non-parametric Kruskal-Wallis test indicates a significant difference between years for all seven ions (Table 3) and the Mann-Whitney test indicates a significant difference between the use or not of TWW for irrigation for all ions except K (Table 5); however, the Mann-Whitney test indicated significant differences between the two depths only for Mg and Cl (Table 4). The trend over the years is not the same for all ions. Thus, there is an ever increase over the years for Na and K while there was an increase in 2016 followed by a decrease in 2017 for P, Mg, Ca, and Cl; on the other hand, there was a continuous decrease for Nt (Table 3). For the depths, we notice a decrease between the surface and in depth for the two ions Mg and Cl (Table 4). The same behavior as the previous one is also found for the use of TWW with an increase from the control plot to the irrigated one (Table 5).

The results showed that the quantities of Na in the plots irrigated with TWW increased significantly over time from 1.95 (2015) to 2.45 mg/Kg (2017). Such a result has been found elsewhere Halliwell et al. (2001). For Cl, the concentration increased from 34.51 (2015) to 81.23 mg/Kg (2017). Even if the water used has a low concentration of Cl, it caused a significant variation in the accumulation of Cl in the plot irrigated by TWW Rengasamy, (2010), with a low accumulation of Na for the depths of 2.10 mg/Kg (in surface) and 2.27 mg/Kg in (in depth) (Table 4). Such a result was found in another study Halliwell et al. (2001), on the other hand, there was a more significant Cl leaching towards the depth (51.02 mg/Kg) (Table 4). Sodium is one of the most serious specific toxic ions of concern. It is reported that sodium directly affects the availability of crop water and causes unfavorable physicochemical changes in the soil (Richards, 1954; Aubert, 1983; Tessier, 1984), especially in soil structure. It has the ability to disperse soil, which reduces permeability, lowers shear strength and increases compressibility (Chang et al., 2005; Al-Jasser, 2011), and negatively affects plant growth (Shaheen et al., 2013; Shahbaz et al., 2011; Pereira et al., 2011).

The median values of Ca and Mg were higher in soils irrigated by TWW in 2016. This accumulation indicates that the adsorption of these elements on the exchangeable complex was greater than the uptake by plants Bedbabis et al. (2014), and depending on climatic conditions, can also be explained by the high concentration in TWW during the irrigation period (Table 1). At the end of the treatment period (2017), a significant decrease in Ca and Mg was observed, this could be due to rain Laribi, Alzubaidi (2007). In this context, it is possible to conclude that TWW did not promote a rapid increase in the Ca content in the soil and also the migration to the depth is not significant Urbano et al. (2015), on the other hand, the migration of Mg to depth is significant.

Median K values ranged from 8.68 mg/kg (2015) to 12.45 mg/kg (2017) with a significant increase over time (Table 3). This increase was directly caused by the K content in the irrigation water and also the density of vegetation covers present during the sampling time. These results are in agreement with others (Emongor and Ramolemana, 2004; Heidarpour et al., 2007; Arienzo et al., 2009). By comparing these concentrations with the standards, these soils are very poor Riquier (1966).

Monitoring K shows no significant change after irrigation (Table 5) (Bazza and Xanthoulis, 2003; Mouhanni et al., 2011). Stability between horizons was probably a consequence of the uptake or displacement of K from the soil solution to the plant because the K element did not move quickly in the soil profile Nasini et al. (2013). However, the presence of K in high concentration can have several economic advantages by reducing the use of fertilizers Di Serio et al. (2008).

The results obtained for Nt and P during the three years reveal a significant decrease recorded at the end of the experiment (2017) (Table 3), with a slight increase in P between the first two years irrigated by TWW of 17.05 mg/Kg (2015) and 19.46 mg/Kg (2016). This is an indication that TWW irrigation increased soil P (Akponikpè et al., 2011; Emongor and Ramolemana, 2004; Heidarpour et al., 2007). Despite the high Nt concentration of TWW, there was a significant decrease in the total nitrogen content during the treatment period due to subsequent consumption by the presence of grass since Nt and P are considered important nutrients for plant growth (Mouhanni et al., 2011; Sacks and Bernstein, 2011; López-Piñeiro et al., 2008) and soil wiping by rainwater Boulahbal (2011). It is observed that the concentrations of Nt and P in the surface layer are lower than those in depth, so there was anon significant leaching in the layers probably due to the method of irrigation and the soil capacity of adsorption (Miller et al., 1980; Jnab et al., 2001; Oron et al., 1992).

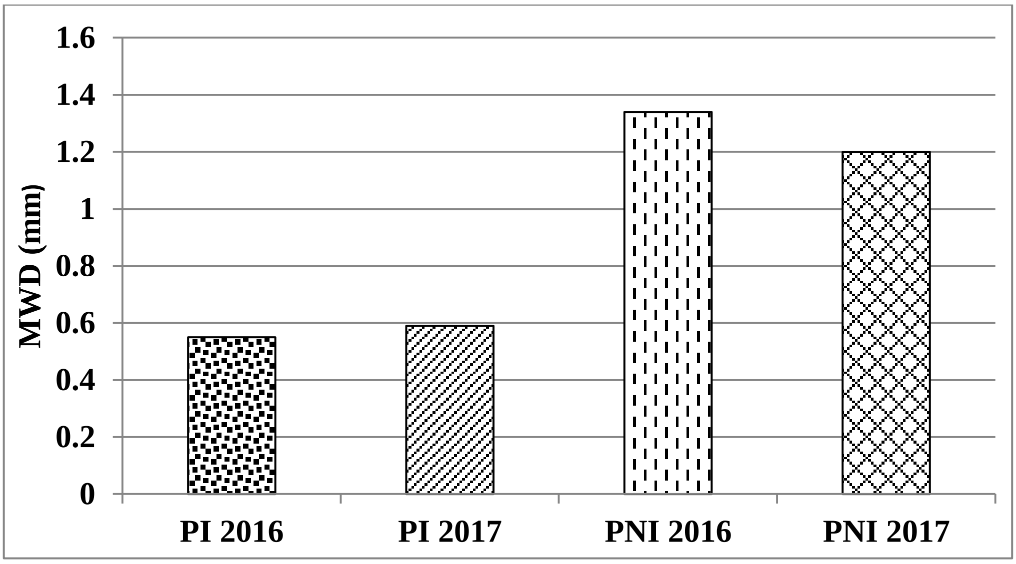
ESP and SAR.

Regarding ESP and SAR, there were significant differences between years (Table 3) and depths (Table 4) but not between the use or not of TWW for irrigation (Table 5). In this study, the median values of ESP and SAR in soils irrigated by TWW reveal an increase recorded at the end of the experiment (2017) (Table 3). A similar result has been found in other studies (Gharaibeh et al., 2007; Warrington et al., 2007; Sou et al., 2013; Galavi et al., 2010). The increase in ESP corresponds to a linear increase in the SAR values of the plot irrigated by TWW (Harron et al., 1983; Bower, 1959; Gharaibeh et al., 2016). In all cases, all the measured values are lower than the limit for a soil to be considered sodic when they present a SAR greater than 13% or an ESP greater than 15% (Sumner, 1993; Legros, 2007; Richards, 1954). However, when monitoring the work, the values of ESP and SAR increase significantly in depth for the plot irrigated with TWW. These results are in agreement with several research works Stevens et al. (2003). The evolution of SAR and ESP at depth is linked to the leaching of salts between irrigation periods. In such contexts, the extent of salt leaching from soils is known to be related to salt solubility, irrigation volume, rate of ion migration, and soil permeability (Tedeschi and Dell'Aquila, 2005; Levy et al., 2003). ESP and SAR values did not indicate saturation of the soil exchange complex with sodium ions, but there are other indicators responsible for ESP and SAR. This result showed that Na accumulation is low in soils irrigated by TWW. Similar results were found Urbano et al. (2015). However, increasing the concentrations of bicarbonates in irrigation water (TWW), with an average value of 315 mgl/l due to their combination with Ca or Mg ions, leads to the formation of a precipitate of Ca or Mg carbonate in the soil, and with an average chloride content of 290 mg/l in irrigation water (TWW). This causes increased Na content and SAR (Ayers and

Westcot, 1985; Feigin et al., 2012). No significant difference was observed between the irrigated plot and the control plot, there is a small increase for the soils irrigated by TWW compared to the control soil. It could be postulated from the duration of treatment by TWW (three years) and by the lower OM concentration in the treated soils can lead to complexation of cations which has an important role in the increase or the decrease of the ESP and SAR (Oster and Rhoades, 2018; Metzger et al., 1983; Feigin et al., 1991).

Structural stability of soil

Structural stability is an important characteristic of soil and there are several factors responsible for the degradation of aggregate stability (Whelan et al., 1995; Saidi et al., 1999; Dıaz-Zorita et al., 2002). Irrigation with TWW in arid and semi-arid regions poses unique and unknown problems for the farming community, one of which is the possible degradation of soil structure and their stability.



** P1: Plot irrigated by TWW. PN1: Plot not irrigated.*

Fig. 1. *Effects of TWW irrigation on soil structural stability.*

The likely risks of adverse changes in soil structure and stability after irrigation with TWW may arise from higher levels of dissolved organic matter, suspended matter, sodium adsorption rate (SAR) and soil salinity of TWW Levy (2011).To assess the structural stability at the level of the irrigated and non-irrigated soils by TWW, two different years were chosen: the first sample was taken in September 2016 for the two plots and after one year of irrigation by TWW, a second sample was taken in the same plot. The recorded results show stabilization in the soil aggregates with an MWD of 0.55 and 0.59 mm compared to 1.34 and 1.20 mm for the non-irrigated plot (Fig. 1). In our case, the soil is unstable Bissonnais, Souder (1995). In this study, the stability of soils irrigated by TWW was lower than that of non-irrigated soils due to the increase in ESP and SAR. There is a significant difference in the structural stability between the plots irrigated by TWW and those not irrigated. There appears to be no change in structural stability during the TWW irrigation times; the likely conditions preventing the change would be that long-term irrigation with TWW has resulted in some deterioration of stability and coarse and medium textured soils (<25% clay) irrigated with TWW create conditions favoring the dispersal of clay by

increasing sodicity, which seems to play only a minor role in determining the stability of aggregates Kemper, Koch (1966), and also related to the intensity of turf cultivation Levy et al. (2006).

Conclusion

The reuse of TWW in semi-arid regions, such as Ain Defla (Algeria), is a key strategy to protect the sustainability of natural water resources. From an environmental point of view, in general and specifically pedological, irrigation by TWW has led to a modification in the characteristics of the soil. The main objective of this work was to examine the impacts of treated wastewater on the physicochemical characteristics of soils. The analyzes performed as a function of time result in much more significant changes in the chemical compositions of the soil. There is an increase in pH and electrical conductivity in the soil profile, depending on irrigation water concentrations (TWW) and climatic conditions. At the same time, there is a moderate increase for major elements such as Na, P, K, Ca, and Mg; however, these concentrations are reduced due to several factors, including climate (precipitation), irrigation water ion concentration (TWW), and the presence of vegetation cover, as is the case with total nitrogen which is considered among the main nutrients of plants. Also, a significant increase with time and frequency of TWW irrigation was observed for SAR and ESP. Although we did not notice any change in the physical appearance of the soil such as structural stability, this is due to the short period of irrigation, hence the impact of seasonal TWW irrigation to see variations in chemical appearance and long-term for the physical aspect of the soil. We should not forget, either, the season and the time of irrigation, the irrigation system, the frequency of irrigation and the quality of irrigation water which are the primary factors that determine the risk of physical and chemical degradation of soil. Therefore, it is not possible to use TWW as an alternative source of irrigation water without considering the factors mentioned above.

Contributions of authors

Rata Y and **Douaoui A** designed and performed the experiments, performed the statistical analysis and also wrote the original manuscript. **Douaoui A**, **Rata M**, and **Douaik A** reviewed the manuscript. All authors have read and approved the final manuscript.

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Toposequence Study of Soils along Donga River in Manya, Takum Local Government Area Taraba State, Northeast Nigeria.

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Abstract

A toposequence soils study was undertaken along Donga River in Manya, Takum LGA Northeast Nigeria. Three (3) profile pits were sunk using physiographic positions (upper slope, mid-slope and valley bottom) and the soil samples were collected based on genetic horizon differentiation, the samples were subjected to routine laboratory analysis. Data generated was analyzed statistically using coefficient of variance and weighted mean. All profile pits were geo-referenced using hand held GPS receiver. Soil colour ranged from dark brown (7.5YR 3/2) in the Ap horizons to strong brown (7.5YR 5/8) in the Bt horizons. Sand and silt dominated the fractions (sand mean content 43.00 g/kg-^{1}, 71.47 g/kg-^{1} and 39.64 for Pedons 1, 2 and 3 respectively and silt mean at Bt2 had 558 g/kg-^{1}, 366 g/kg-^{1} and 680 g/kg-^{1} for Pedons 1, 2 and 3 respectively). The bulk density was higher in the top soils than in the sub soils, the highest mean was recorded in pedon 3 (1.57 g/cm^3). The silt clay ratio (SCR) was indicative of soils with weatherable minerals. The soil pH ranged from moderately acid to slightly acid (6.48, 5.80, 5.95) in pedons 1, 2 and 3 respectively. The negative ΔpH values obtained are indicative that the colloidal fraction had exchangeable capacity. The total nitrogen was rated low while available phosphorus was rated very high to high. The percentage base saturation had mean from 96.72%, 97.12% and 95.79% in pedons 1,2 and 3 respectively, suggestive of Alfisols -Entisols mix. There were varied results for coefficient of variation (CV) in soil properties among the different positions on the toposequence. Therefore, the soils were classified as Typic Isohyperthermic Haplustalfs in pedons 2 and 3 with fluvic characters in pedon 1 (USDA) which corresponded to Arenic Luvisols (WRB).

Key words: Toposequence, Landuse, Soil Profile, Soil Classification, Northeast Nigeria

Introduction

The spatial distribution of soil types is related to the topography. The relationships between relief and soil formation processes are manifold (Ojo-Atere et al., 2011). Toposequence and catena concepts have emanated as slope-soil evolutionary processes. However, there is great need to evaluate the toposequence of the soil in order to examine its physical, chemical and biological properties of the soil. Brady and Weil (2014) described toposequence as a sequence of related soil that differ, one from the other, primarily due to topography as a soil forming factor. Soil properties are important to define and evaluate soil types, slope aspects, existing landuse etc. The sustainability and productivity of soil depends on its changing equilibrium in the physical, chemical and biological properties. These properties are spontaneously affected by landuse with profound influence on soil properties and thereby enhancing the restoration of soil quality (Deekor, 2012). Topography as a factor in soil formation is classified as passive factor by Asadu et al. (2011). However, understanding of the impacts of landuse on soil property is indispensable for sustainable agricultural production (Fesha et al., 2002). Spatial variability, parent materials, physiographic position (position of soils on a toposequence) and drainage condition will influence soil fertility and landuse pattern in any given demographic location (Imadojemu, 2021). Soil variation occurs naturally due pedogenic processes, for example soils from summit of a toposequence down to the valley bottom. The movement and transformation of nutrient in soils are influenced by climate and topography (Klemmedson & Weinhold, 1991). Seibert et al. (2007) reported significant correlation between topographic indices and soil properties while Temgoua et al. (2005) concluded that topography is both an internal and external factor in pedogenesis and accounted for about 60% variation in soil properties. The differences in properties of soil occupying different landscape position on a toposequence are caused by water and material movement and distribution along a slope. However, (Moorman, 1981) stated that the different landscape position influence runoff, drainage, erosion and thus dictates soil genesis. The extent of runoff and erosion dictates the surface movement and distribution of basic cation. Soils especially in the tropics are formed in different section of the topography. The rate of soil formation varies along the various segment of the topography such as the crest, middle slope, lower slope and valley bottom as the result of deposition of materials in the various sections of the landform (Osodeke, 2017). Birkeland, (1999) described the soil catena as a chain, string, or a connected series of soils, related by their sequence in the landscape. Therefore, the variability of soils in a topographic sequence is a function of gradient and position on slope and hence a function of time (McFarlane, 1991). Catenary soil sequences occur on hill slopes where the geology is uniform and there is no marked difference in climate from the top to the bottom of the slope. Rather, variations in soil profiles that occur down the slope are largely the result of the changes in slope gradient. Landuse according to Akamigbo (2010) is simply the

activities to which man has put land in order to generate economic output or result while FAO (1984 and 1997) defined landuse as the arrangement, activity and input people undertake in a certain land, it involves the cover type to produce it brings, change or maintenance of it. Land that is suitable for agricultural production is finite and vulnerable resource. Senjobi (2001) noted that the practice in developing nation's landuse (soil) is often not related to the capacity of the land for that use. Therefore, assessing the spatial variability of soil properties is crucial to sustainable farming practices and reducing the knowledge gap in soil resources management. This study is aimed at determining the properties of soils along the toposequence of Donga River in Manya with a view to classifying the soil for agricultural production

Materials and Method

Study Area

The study was carried out in Manya, Takum Local Government, Taraba State Northeast Nigeria. The area lies between Latitude 7^0 15'N to 7^0 45'N and Longitude 9^0 59'E to 10^0 25'E of the Greenwich meridian. It is largely governed by Inter Tropical Convergence Zone (ITCZ) defined by two opposing air masses; both the Southwesterlies and the Northeasterlies trade wind (Okusami et al., 1987). It is characterized by hot, sub humid and humid conditions. The area has a tropical hot and wet weather with distinct rainy season (May – October) and dry season (November – April); (Aw Koppen's climate classification); as modified by Peel et al (2007). Annual rainfall ranges from 1218-1480 mm and the rainfall pattern is relatively weak bimodal trend (transitional belt between the rain forest and the southern guinea savanna zones). The mean annual temperature is about 29°C indicating the tropicality of the environment and characterization of the climate area as hot (temperature can reach 40°C in March) (Imadojemu, 2021). The temperature of the area, although vary slightly annually and seasonally, remains high throughout the year. Therefore, temperature during the growing season is not a limitation to the adapted crops of the area. In the dry season, minimum and maximum temperatures are generally lower during the harmattan months in most cases, but higher than those for the rainy season during the rest of the season. The relative humidity varies as the rainfall pattern and rate of potential evapotranspiration follows the trend of the relative humidity. The hydrology is governed by Donga River. The major economic activity in the area is farming largely at low to medium scales alongside timber (*Pteracarpuserinaceous*) harvesting.

Vegetation

The area falls within the Agro-ecological zone of woody Savannah vegetation which consists of shrubs, tall grasses (>2 m) and trees especially along the river bank. It also consists of secondary forest regrowth. The area consists of some tree crops such as Oil palm, Mango, Banana, Cocoa and Gmelina arborea while the cultivated crops in the area include Maize (*Zea may*), Cassava (*Manihot spp*), Rice (*oryza sativa)*, Fluted pumpkin (*Telifera occidentalis*), Banana (*Musa spp*). Ground nuts (*Arachis hypogeal*), cowpea (vigna ungiculata), are produced in large quantities.

Geology and Soil

The geology of the study area is characterized by cretaceous sediments to pre-Cambrian to Cambrian undifferentiated basement complex and such as sand stone materials are the dominant parent materials. The soil found in the study sites are largely the tropical alfisols or luvisols.

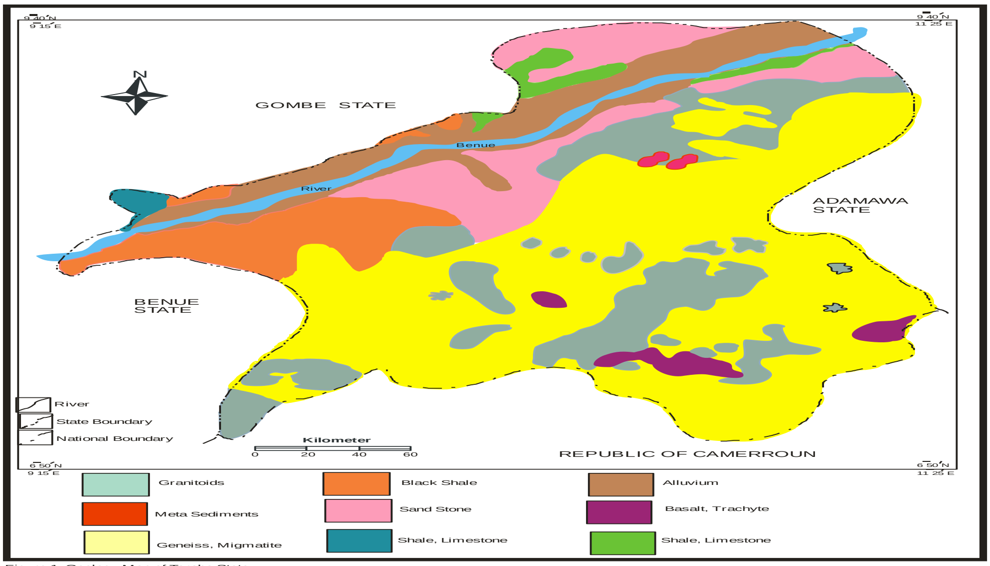

Figure 1: Geology Map of Taraba State
Source: Ministry of Lands and Survey, Jalingo, Taraba State.

Figure 1. *Geological Map of Taraba State*

Field Activities

Reconnaissance survey was carried out in order to obtain general information about the study area. The toposequence were delineated into mapping units based on their physiographic positions (upper slope, mid-slope and valley bottom) along transect spaced at 400 m across the slope. These slope positions also corresponded to different landuse upon which three profile pits were sunk according to the procedures of Soil Survey Staff, (2006). Sampling was based on genetic horizon differentiation. All profile pits were geo-referenced with hand held GPS receiver.

Sample Preparation

The soil samples were air dried at room temperature of 25^{0}C for about three days, after which they were sieved using a 2 mm sieve mesh. Some part of the soil samples were passed through 0.5mm mesh sieve for Organic Carbon (O.C) and Total Nitrogen determination.

Laboratory Analysis

Particle size analysis was determined using the Bouyoucos hydrometer method as modified by (Gee and Or, 2002). Bulk density was determined by core method (Grossman and Reinsch, 2002). The moisture content was determined after oven-drying of core soil samples and amount of moisture content was calculated as follows: W_1 =weight of can with lid W_2 =weight of soil+ weight of can with lid, W_3 =weight of oven-dry soil. Total porosity was determined using the formulae

$$\text{Porosity (F)} = 100 - \left(\frac{e_b}{e_s}\right) \times \frac{100}{1}$$

Where e_b = bulk density (g/cm^3)

e_s = particle density (2.65g/cm^3)

The soil pH was determined electrometrically using pH meter and this was done in distilled water and 0.1N KCl solution using a sol liquid ratio of 1:2.5 in a glass electrode (Thomas, 1996). Total nitrogen was determined by micro Kjeldahl digestion method (Bremer, 1995). Organic carbon was determined by wet digestion method (Nelson & Sommer, 1982). Available phosphorus was determined using Bray II method as described by (Olsen & Sommer, 1982). Exchangeable acidity was determined by leaching the soil with 1N KCl and titrating with 0.05N NaOH (Mclean, 1982). Exchangeable basic cation($Ca^{+2,}$ Mg^+, K^+, Na^+) was determined using 1N NH^4OAC buffered at pH of 7, while K and Na are by flame photometer (Udo, et al., 2009) and Ca and Mg by Atomic Absorption Spectrophotometer (AAS). Cation exchange capacity (CEC) was determined by ammonium acetate (NH_4OAc) of 1.0M leaching at pH 7 (Blackmore et al., 1987). The available Iron (Fe), Zinc (Zn), Copper (Cu), and Manganese (Mn) were extracted with DPTA-TEA buffer (0.005M DTPA+ 0.01M CaCl2 + 0..1M TEA at pH 7.3) as described by Verma et al. (2005). The leachate concentration of Zn, Fe, Cu, and Mn were determined using AAS.

Statistical Analysis

Variability amongst selected soil properties was analysed using coefficient of variability coefficient of variation (CV) was ranked according to procedure of Wilding et al., (1994) where CV ≤ 15% represents low variation, CV 15≥ % ≤35% (moderate variability) and > 35% (high variation). The mean values were obtained using weighted mean.

Results and Discussion

The Morphological Properties

The morphological properties of Manya toposequence soils are shown in the table 1. The soil are moderately deep (≥ 100 cm) and porous, the entire horizon were well drained. The soil was loose at all physiographical positions. Pedons 1, 2 and 3 had a fine granular structure in horizon Ap, weak, medium sub-angular structure in horizon AB, angular and sub-angular blocky structure in horizon Bt1 and Bt2 respectively. The profiles on physiographical positions varied in colour matrix. Pedon 1, had dark brown colouration (7.5YR 3/2) in the Ap horizon brown colouration (7.5YR 5/3) in the AB horizon, with brown colouration (7.5YR 5/2) with a lighter chroma in the Bt1 horizon and light grey colour (5YR 7/1) in the Bt2. Pedon 2 recorded a reddish brown (2.5YR 4/3) in its Ap horizon while brown colour (7.5YR 4/4) was observed in the AB horizon whereas a dark reddish brown (2.5YR 3/3) and a brown (10YR4/3) were observed in Bt1 and Bt2 horizons respectfully. Pedon 3 had dark reddish brown (2.5YR 2.5/4), strong brown (7.5YR 5/8), pink (7.5YR 7/3) and pinkish white (7.5YR 8/2) in its genetic horizons of Ap, AB, Bt1and Bt2 respectively. The colour metix and other morphological characteristics of the soil suggest that the soils are under the same pedogenic processes. The colour metrix of dark yellowish brown, strong brown and reddish yellow are associated with minerals such as Goethite (FeOOH) and Haematite (Fe_2O_3). The sub angular and angular structures found in the Bt horizons are indicative of illuviation processes (Imadojemu, 2021).

The Physical Properties

The physical properties on the studied pedons are presented in table 2. It was observed generally that the contents of sand and sillt fractions dominated the soil peds. The higher content of silt over clay indicates that the soil has reserved weatherable mineral. This has a positive implication for soil fertility status as about 50% of the textural class in the study area were silty loam while about 43% were sandy loam. The preponderance of loamic texture connotes higher nutrient retention. Mean sand content were 43.00 g/kg-^{1}, 71.47 g/kg-^{1} and 39.64 for Pedons 1, 2 and 3 respectively. The highest values of silt were observed at the Bt2 horizons at 558 g/kg-^{1}, 366 g/kg-^{1} and 680 g/kg-^{1} for Pedons 1, 2 and 3 respectively. The proportion of clay decreased with increase in profile depth. The SCR mean for Pedons 1, 2 and 3 were 38.61, 93.11 and 67.55 respectively. Yakubu and Ojanuga, (2009) reported that SCR below 0.15 was indicative of an old soils (senile) while SCR above 0.15 was indicative of a young soil with weatherable reserves. Bulk density (in g/cm^{3}) tends to be higher in the top soils; this may be due to anthropogenic activities. The mean bulk densities were

Table 1: *Morphological Properties of the studied soils*

CO-ORDINATES	HORIZON	DEPTH (cm)	COLOUR (moist)	STRUCTURE	MOTTLE	HORIZON BOUNDARY	TEXTURE	CONSIST.	VEG	ROOT PRES.
Rice Landuse (Pedon 1) (Valley bottom)										
	Ap	0-14	Dark brown 7.5YR3/2	Granular	Few	Clear, smooth	Fine	Friable	SR	Many
$7^{0},19^{0},15^{0}$N	AB	14-40	Brown 7.5YR5/3	Sub-angular	Very few	Diffuse, wavy	Fine	Firm	SR	Few
$10^{0},14^{0},45^{0}$E	Bt1	40-70	Brown 7.5YR5/2	Angular	Many	Clear, smooth	Fine	Very firm	SR	Very few
	Bt2	70-100	Light grey 5YR7/1	Sub-angular block	Many	Clear, smooth	Fine	Firm	SR	Absence
Cassava Landuse (Pedon 2) (Mild slope)										
	Ap	0-13	Reddish brown 2.5YR4/3	Granular	Very few	Clear, wavy	Coarse	Friable	SR	Many
$7^{0},19^{0},16.2^{0}$N	AB	13-50	Brown 7.5YR4/3	Sub-angular	Common	Clear, wavy	Coarse	Firm	SR	Few
$7^{0},19^{0},46.5^{0}$E	Bt1	50-70	Dark reddish brown 2.5YR3/3	Sub-angular block	Common	Common	Very fine	Firm	SR	Very few
	Bt2	70-100	Brown 10YR4/3	Angular	Common	Common	Fine	Firm	SR	Very few
Mixed Crop Landuse (Pedon 3) Summit slope										
	Ap	0-20	Dark reddish brown 2.5YR2.5/4	Granular	Many	Clear, smooth	Coarse	Friable	SR	Many
$7^{0},19^{0},14.2^{0}$N	AB	20-56	Strong brown 7.5YR5/8	Sub-angular	Few	Clear, smooth	Coarse	Firm	SR	Few
$10^{0},14^{0},43.3^{0}$NE	Bt1	56-80	Pink 7.5YR7/3	Blocky	Few	Clear, smooth	Fine	Hard	SR	Few
	Bt2	80-110	Pinkish brown 7.5YR8/2	Angular	Common	Clear, smooth	Fine	Hard	SR	Few

All colour were taken under moist condition, SR: Secondary Regrowth, Consist: Soil consistency

1.24 g/cm^3, 1.39 g/cm^3 and 1.57 g/cm^3 for pedons 1.2 and 3 respectively. The values obtained for bulk density agrees with those earlier reported by Imadojemu *et al* (2017) and Obasi *et al* (2021) while Esu (2010) reported that bulk density value less than 1.60 gcm-^{3} is an indication that air and water movement in the soil are at optimum. The mean values for porosity showed that the soil root zone had no impediments to gaseous exchange. Porosity normally have inverse relationship with bulk density and both have profound effect on infiltration, rooting depth, soil aeration, available plant water and soil microbial functions.

Table 2. *Physical Properties of the Studied Soils*

Horizon Designation	Depth (cm)	SAND g/kg-^{1}	SILT g/kg-^{1}	CLAY g/kg-^{1}	SCR	TC	BD (g/cm^{-3})	Po (%)	MC (%)
RICE LANDUSE (Pedon 1)									
Ap	0-14	514	432	54	8	Sandy loam	1.16	56.6	8.5
AB	14-40	332	646	22	29.36	Silt loam	1.36	48.7	11.59
Bt1	40-70	472	516	12	43	Silt loam	1.26	52.65	13.7
Bt2	70-100	434	558	10	55.8	Silt loam	1.19	55.09	13.95
Mean		430	550	19	38.61		1.24	53.26	12.5
CV		143	110	105.85	52.8		15	47.53	20.85
CASSAVA LANDUSE (Pedon 2)									
Ap	0-13	71.12	24.2	4.6	5.26	Sandy loam	1.67	36.98	25.55
AB	13-50	75.2	24.2	0.6	40.33	Sandy loam	1.19	55.09	25.13
Bt1	50-70	77.2	22.6	0.2	113	Loamy sand	1.39	47.54	25.91
Bt2	70-100	63.2	36.6	0.2	183	Sandy loam	1.32	50.2	11.97
Mean		71.47	27.6	0.92	93.11		1.39	47.45	21.39
CV		8.67	23.77	240.46	85.43		11.44	50.51	31.98
MIXED CROP (Pedon 3)									
Ap	0-20	51.2	48.2	0.6	80.33	Sandy loam	1.43	46.04	12.21
AB	20-56	43.2	56	0.8	70	Silt loam	1.53	42.3	25.16
Bt1	56-80	35.2	62.8	2	31.4	Silt loam	1.66	37.36	15.34
Bt2	80-110	31.2	68	0.8	85	Silt loam	1.67	36.98	13.33
Mean		39.64	59.34	1.02	67.55		1.57	40.67	17.44
CV		22.44	1450	6250	36.07		10.33	25.86	34.45

SCR: silt clay ratio, Po: porosity (%), MC: moisture content (%), TC: Textural Class

The Chemical Properties

The chemical properties of the soils are shown in table 3. The soil pH (water) had mean values of 6.48, 5.80, and 5.95 in Pedons 1, 2, and 3 respectively. Pedon 1 had the mean with the least acidity mean value (6.48), while Pedon 2 had the highest mean with value (5.80). The acidity increased down the profile, the soil pH in water ranged from moderately to slightly acid which is ideal for most crop production according to the rating of Chude et al., (2011).

Table 3: *Chemical Properties of the Studied Soils*

Depth (cm)	pH H2O	pH KCl	ΔPH	OC	TN	C/N Ratio	Av.P (Mg/Kg)	Ca	Mg	K	Na	ECEC	TEB	TEA	Ca/Mg Ratio	%BS	Zn	Fe	Cu	Mn
				%				cmol/Kg									(mg/Kg)			
Rice landuse (Pedon 1)																				
0-14	7.05	4.25	-2.8	1.95	0.85	2.29	96.75	4.5	0.81	1.41	2.17	9.04	8.89	0.15	5.56	98.34	0.03	0.03	0.02	0.08
14-40	6.75	4.05	-2.7	0.59	0.75	0.79	92.24	4.61	0.81	1.66	2.21	9.64	9.29	0.35	5.69	96.37	0.03	0.03	0.02	0.27
40-70	6.6	3.95	-2.65	0.62	0.95	0.65	122.21	4.5	0.82	1.99	2.18	9.74	9.49	0.25	5.49	97.43	0.02	0.03	0.02	0.18
70-100	5.85	4.05	-1.8	0.47	0.65	0.72	98.94	4.5	0.81	1.53	2.04	9.23	8.88	0.35	5.56	96.21	0.02	0.03	0.02	0.27
mean	6.48	4.05	-2.43	0.75	0.79	23.43	103.87	4.53	0.81	1.69	2.14	9.46	9.17	0.29	5.57	96.92	0.03	0.03	0.02	.21
CV	4.78	-33.4	40.84	40.84	2.41	28.8	10.6	18.71	18.65	6.41	42.6	17.14	6.3	18.65	0.88	16.33	25.85	25.87	14.93	25.87
Cassava Landuse (Pedon 2)																				
0-13	5.95	4.25	-1.7	1.15	0.95	2.1	97.04	4.6	0.81	1.92	2.27	9.75	9.6	0.15	5.68	98.46	0.02	0.03	0.02	0.08
13-50	5.85	4.05	-1.8	0.68	0.75	0.91	89.13	4.5	0.82	2.34	2.31	10.32	9.97	0.35	5.49	96.61	0.02	0.03	0.02	0.28
50-70	5.75	4	-1.75	0.3	0.85	0.35	67.14	4.6	0.81	2.37	2.27	10.25	10.05	0.2	5.68	98.05	0.02	0.03	0.03	0.12
70-100	5.7	3.95	-1.75	0.95	0.95	1.00	54.61	4.6	0.81	1.97	2.42	10.15	9.8	0.35	5.68	96.55	0.02	0.03	0.03	0.27
Mean	5.8	4.04	-1.76	0.75	0.86	24.49	75.4	4.56	0.81	2.18	2.33	10.18	9.89	0.29	5.61	97.12	0.02	0.03	0.02	0.22
CV	12.49	36.46	55.44	55.45	1.11	23.63	10.67	53.19	34.81	32.57	37.88	53.33	62.89	31.02	34.42	70.59	21.19	24.97	23.16	32.78
Mixed Crop Landuse (Pedon 3)																				
0-20	5.7	4.05	-1.65	0.12	0.25	0.48	14.27	4.6	0.82	1.67	2.37	10.03	9.48	0.55	5.61	94.52	0.02	0.03	0.02	0.48
20-56	5.65	3.85	-1.8	0.74	0.2	3.7	12.22	4.5	0.82	1.58	2.46	9.86	9.36	0.5	5.49	94.93	0.02	0.03	0.02	0.43
56-80	5.65	3.9	-1.75	0.65	0.15	4.33	12.19	4.9	0.81	1.63	2.46	10.2	9.8	0.4	6.05	96.08	0.02	0.03	0.03	0.33
80-110	6.7	3.85	-2.85	0.62	0.1	6.2	11.76	4.72	0.81	1.59	2.37	9.74	9.49	0.25	5.83	97.43	0.02	0.03	0.03	0.17
Mean	5.95	3.9	-2.05	0.58	0.17	26.04	12.46	4.67	0.82	1.61	2.42	9.93	9.51	0.42	5.73	95.79	0.02	0.03	0.03	0.35
CV	12.69	9.05	40.03	34.62	36.44	1.85	25.87	4.08	24.2	14.29	13.93	54.9	26.85	18.37	32.04	1.04	17.83	29.06	25.28	10.96

C/N: Carbon Nitrogen ratio, OC: Organic Carbon, TN: Total Nitrogen, ECEC: Effective Cation Exchange Capacity, TEB: Total Exchangeable Bases, TEA: Total Exchangeable Acidity, AvP: Available Phosphorus

The pH in KCl had mean values of 4.05, 4.04 and 3.90 in Pedons 1, 2 and 3 respectively. The negative ΔpH values obtained are indicative that the colloidal fraction has exchangeable capacity- cation exchangers (Imadojemu, 2021). The mean of the total Nitrogen (TN) had a value of 0.79%, 0.86% and 0.17% in Pedon 1, 2, and 3 respectively. Highest mean (0.86%) was observed in Pedon 2, while the lowest mean had a value of (0.17%) recorded in Pedon 3. The percentage of nitrogen was rated very low based on soil fertility classes for Nigerian soils (Onyilola and Chude, 2010; Chude et al., 2011). The low values obtained in pedon 3 (summit slope) may be due to its physiographic position. The C:N is important for determining mineralization and immobilization of nitrogen, C:N of ≤ 25 is reported to favour mineralization of organic matter by soil microbes. The Available phosphorus had a mean of 103.87 mg/kg, 75.40 mg/kg and 12.46 mg/kg in Pedon 1, 2, and 3 respectively. The highest mean (103.87 mg/kg) was recorded in Pedon 1. The available phosphorus in the soil was rated very high. For Calcium, an estimated mean of 4.53 cmol/kg, 4.56 cmol/kg and 4.67 cmol/kg in Pedon 1, 2 and 3 respectively. Sodium (Na) had a mean range of 2.14 cmol/kg, 2.33 cmol/kg and 2.42 cmol/kg in Pedon 1, 2, and 3 respectively. The ECEC was dominated by Ca and Na. However, high content of Na did not constitute any threat to crop production. The ECEC had mean value ≥ 9 cmol/kg which is rated high and also evidence of 2:1 clay minerals (Ukaegbu et al., 2015). Percentage Base Saturation had a mean that ranged from 96.72%, 97.12% and 95.79% in pedons 1,2and 3 respectively. These high percentage base saturations are suggestive of Alfisols-Entisols mix. The mean for the proportion of manganese in the Pedon had values 0.21 %, 0.22% and 0.35 % in Pedon 1, 2, and 3 respectively. The mean values obtained for Mn, Cu, Fe and Zn were relatively low and does not pose any deleterious effect to agriculture landuse. This low level of micronutrient was also reported by Zaku et al. (2011).

Taxonomic Classification

The soils of the study area were classified using USDA Soil Taxonomy system (2015), and correlated with World Reference Base (2006). In classifying these soils, certain criteria were considered. This include the nature of the epipedon, the types of diagnostic master horizon, the clay content, the organic matter content, the percentage base saturation, the presence or absence of concretions (plinthitic features), the soil moisture, temperature regimes and soils colour. The soils tends to have more bright hues (reddish brown) due to good aeration, these pedons was classified as in the order as Alfisols/ Entisols mix because of the presence of Bt horizon and the absence of lamellae, suborder as utsalfs owing to the ustic moisture regime, great group as Argillic Haplaqualfs as the most horizons are argillic along with high OC contents as well as the high %BS while the preponderance of sand showed psammentic (USDA) correlates to Arenic (WRB). The subgroup was classified Eutric Siltic Haplustalfs. The family was classified coarse Silty Loam, Superactive Isohyperthermic, ustalfs. Series was Manya Silty Loam. This corresponds to Arenic Luvisols (pedons 2 and 3) with fluvic characteristics in pedon 1 (WRB, 2006).

Conclusion

The results of the morphological, physical and chemical properties of the soil showed variability in profile depths and physiographic positions. The profiles were moderately deep, well drained and silt fraction dominated other fractions of the soil. The presence of Bt horizons of silt loam texture indicated that the soil had reserved weatherable minerals. The bulk density and porosity of the soil were within range for good crop cultivation. Soil pH was moderately acid to slightly acid, organic matter was generally low in all the pedons. Available phosphorus ranged from very high to high**.** Therefore, the soils were classified as Typic Isohyperthermic Haplustalfs in pedons 2 and 3 with fluvic characters in pedon 1 (USDA) and Arenic Luvisols (WRB)

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Hydrogeological and Geotechnical Assessment of Gully Erosion Sites in Parts of Uturu, Southeastern Nigeria

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Abstract

This study aims at assessing the hydrogeological and geotechnical characteristics of gully erosion sites in Uturu and environs. Standard hydrogeological and geotechnical investigation methods were adopted in this study. Field geological study of the area revealed that it is covered by sedimentary rocks. The soils are lateritic and are the product of intensive weathering that occurs under tropical and subtropical climatic conditions resulting in accumulation of hydrated iron and aluminum oxides. Results of sieves analysis show that the soils at the gully sites having sorting values ranging between 0.42 and 2.3 coefficient of uniformity values ranging between 3.0 and 10, and the coefficient of curvature values ranging between 0.2 and 1.3. These indicate that the soils are fair to well-sorted in places. The plasticity indices values ranging between 11.0 and 29 with mean value of about 20 indicate soils of moderate to high plasticity, slight dry strength and easily friable. Value of maximum dry density ranges between 1.83 g/cm^3 and 2.12 g/cm^3 at optimum moisture contents of between 7.4% and 11.3% reveals that the soils were generally loose. The hydraulic conductivity and transmissivity values as determined from statistical grain size method range between 3.8 x 10^{-4} cm/s to 6.4 x 10^{2} cm/s and 3.8 x 10^{-2} cm^2/s to 9.6 x 10^4 cm^2 respectively. These indicate moderate seepage fluxes and adverse pore pressures and are thus easily erodible. From the geotechnical analysis results, recommendations for erosion control such as aforestation and construction of drainages were suggested.

Keywords: *hydraulic conductivity, geotechnical, erosion, gullies, plasticity, Uturu*

Introduction

Gully erosion is the state in which soil particles are transported through large channels. In some places, gullies carry water for brief periods of time during rainfall but appear as small valleys or crevasses during the dry seasons. It is an environmental hazard that is ravaging the landscape of parts of Uturu and its environs as well as other parts of the country especially Southeastern Nigeria (UNDP, 1995). Researches on gully erosion emphasized the role played by rainfall intensity and runoff models with a passive reference to geology, hydrogeology and geotechnical characteristics of gully sites (Wishchmeier and Smith, 1978; Effiong – Fuller, 2000; Usoro, 1989, Formis et al., 2005; Van Dijk et al., 2005).

The devastating effects of gullying destruction of the environment in various parts of the Eastern Nigeria have also been variously discussed (Grove, 1951; Floyd, 1995; Ofomata, 1965; Ogbukagu, 1976; Nwajide and Hogue, 1979; Nwankwoala and Igbokwe, 2019). They attributed the causes, origin and growth of the gullies to the effects of agriculture, human activities and the geology.

Soil erosion is one of the prominent geological and environmental hazards currently ravaging the land surface of Southeastern part of the country, especially Abia State. It generally degrades land and affects not just plants and animals but is capable of taking away human's life and destruction of properties. The loss of these resources or functions, through erosion is a serious environmental problem. Apart from natural processes, soil erosion is greatly accelerated by anthropogenic activities such as construction of roads and building, logging, mining and agricultural production.

Uturu and its environs is part of Southeastern Nigeria, the underlying geology and soil consist of heterogeneous materials namely basement complex, beach sands, coastal plain sands, mangrove swamp deposits, sandstones, shale, Sambreiro Warri – deltaic deposits, recent and sub-recent alluvian (FDLAR, 1990). According to Egede (2013), the soils of the southeastern Nigeria is are heterogeneous in nature comprising of loose red-earth with sands, sandstones, clayey-loam with or without ferric properties underlain by shale formation. Also reported by Ezemonye and Emeribe (2012), the soils are derived from shale and sandstone parent materials which are deep, porous and acidic with low organic content as a result of leaching from rainfall activity. According to Ufot et al., (2016), southeastern soils are low in organic matter content, base status and water storage capacity with high susceptibility to accelerated erosion and land degradation. Ezezika and Adetona (2011) further states that the soils have low silt / clay content thus resulting in a sandy soil which is cohensionless, very permeable and very high infiltration rates.

With the above points and facts, it is observed that soil erosion is very common in Uturu area of Abia State. The cumulative impact leaves the inhabitants homeless, jobless and miserable. Consequently, the threats posed by gaping and daunting large gullies to farmlands, roads and human settlements are so numerous. Several areas in Abia State as well as Uturu have been devastated by different types of soil erosion ranging from rill erosion to gully erosion. The incidence of gully erosion is a common phenomenon in Uturu and its environs which have several negative effects on the

physical environment, biodiversity, psychological and economic development of the inhabitants. Therefore, there is an urgent need to conserve the environment for sustainable development that hydrogeological and soil test analysis will be carried out in Uturu area of Abia State with a view of providing hydrogeological and geotechnical information on the genesis and expansion of gullies. The information from the study will help suggest appropriate measures to control gully development.

Material and Methods

Study Area

The study area is Uturu in Abia State, Nigeria. Uturu is a town located within latitudes 05.33^{0}N and 06.03^{0}N; in the Northern part of Abia State, Nigeria. It is in the transition from rural to urban status, so it is witnessing many development activities. The population of Uturu has been growing at a high rate over decades, until the last decade. Its present population is about 41,000. It has archaeological importance – in 1977, a team of archaeologists discovered signs of the habitation of early, middle, and late stone Age (Homo erectus).

Uturu is divided into two regions, Ihite and Ikeagha. Ihite comprises Achara and Mba Ugwu (Ugwu – Ogu, Ugwu – Ele, Ngodo, Amegu, Obi – Agu, Nnembi and Aro). Ikeagha comprises Isunabo, Akpukpa, Umu-mara, Nvurunvu, and Ndundu. The area is located at a low relief and valley-like area with a maximum elevation of about 156 m. As a result, runoff is relatively moderate and infiltration rate is high. Groundwater storage has also been in abundance due to adverse climatic condition. Soil erosion has become prominent phenomenon and is ravaging the landscape of the study area. However, investigations carried out by Nwankwo & Nwankwoala, (2018); Egboka et al., (2019) and Obiefuna et al., (1999), have shown that the primary causes of gully genesis and expansion lie in the hydrogeological and geotechnical properties or characteristics of complex aquifer systems. The high hydrostatic pressure in the aquifers produce a reduction in the effective strength of the unconsolidated coarse sands in the walls of gullies leading to intense erosion (Egboka and Okpoko, 1984 and Obiefuna and Nur, 2003). Hence, the development of gullies has caused extensive damage to the environment and has driven many away from their homes and farmlands.

The prevalent vegetation is rain forest and mangrove swamps with two distinct seasons: the dry season which last from November to March, and a wet season which last from April to October (NIMET) 2000 – 2015. The mean annual rainfall is about 2145.90 mm, most of which falls between the months of June to September.

The study area is geologically situated in the Eastern Niger Delta. It geologically fall within two out of eleven geologic units in the area (Amos – Uhegbu et al., 2013). These are Bende – Ameki Formation and the Benin Formation.

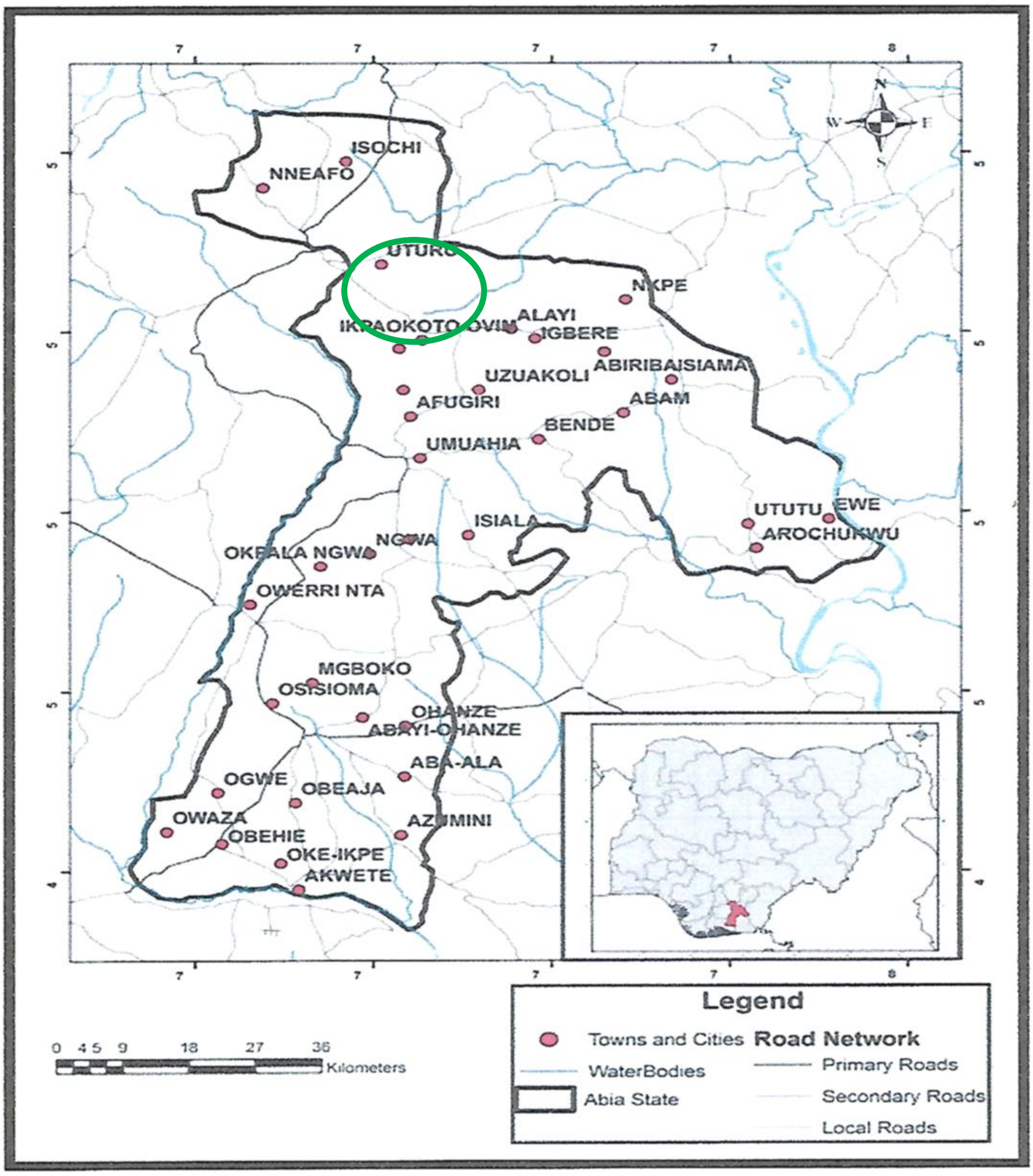

Fig. 1: *Map of Abia State showing location of study area in green circle*

Methods of Study

The soil investigation, which comprised field study and laboratory analysis were carried out. The field investigation for the soil data collection include sampling and measurement in seven different gully erosion sites, with the aid of geologic equipments and Global Positioning System (GPS). Seven true soil representative samples were randomly collected from active erosion sites for laboratory analysis. The soil samples were subjected to laboratory test to determine the hydrogeological and geotechnical properties or characteristics of the soil that facilitates its prone to gully erosion in accordance with standardized methods specified by the American Society for Testing and Materials (ASTM) and the British Standard (BS).

The laboratory tests carried out on the soil samples include Atterberg Limit, California Bearing Ratio (CBR), compaction and Particle Size Distribution (PSD) tests at the Engineering Geology Laboratory, Department of Geology, University of Port Harcourt, Nigeria. Sampling was done between 1 m and 1.5 m from the surface of the gully erosion sites and also utilizes personal observation made during the field mapping and took photographs of the affected areas of gully erosion. Data were presented using various graphical tools and results were recorded as measured by the various instruments.

Result and Discussion

Results Presentation

Table 1. *Gully Parameters and Coordinates as obtained from the field*

Gully Site	Depth (m)	Width (m)	Latitude (N^o)	Longitude (E^o)
Isunabo	5.10	2.60	5.8290707	7.4305303
Umumara	4.00	2.50	5.8305397	7.4183638
Akpukpa	1.50	4.00	5.8304567	7.3997804
Nvurunvu	1.50	3.00	5.8304668	7.3997905
Ndundu	2.30	3.50	5.9385823	7.4255769
Achara	3.30	5.60	5.9351299	7.5550222
Mba-Ugwu	3.50	6.00	5.8295592	7.3933618
Mean value	**3.02**	**3.88**		

Table 2. *Consistency values, optimum moisture content and maximum Dry Density of the samples.*

Sample Location	Sieve Analysis by passing BS 200 (%)	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)	Consistency Index (CI)	California Bearing Ratio (%)	Optimum Moisture Content (OMC)	Maximum Dry Density (MDD)
Isunabo	41.81	46	27	19	2.4	21	9.6	1.96
Umumara	33.1	47	22.5	24.5	1.8	18	7.4	2.09
Akpukpa	38.04	33	20	12.7	2.4	16	11.3	1.97
Nvurunvu	20.92	33	22	11	2.7	24	10.1	1.83
Ndundu	29.44	48	19	29	1.6	16	10.2	1.96
Achara	39.02	45	23	22	1.9	14	9.3	2.02
Mba-Ugwu	36.7	48	27	21	2.2	8	7.4	2.12

Table 3. *Meteorological data for Uturu and Environs monthly rainfall (mm) from 2000 / 2001 – 2014 / 2005 water year.*

Year	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb	Mar.	Total
2000/01	164.5	153.6	265.5	265.2	216.9	277.5	228.4	75.9	3.8	0	7.8	175.9	1835
2001/02	224.1	194.3	522.7	273.5	179	317.2	277.1	18.6	0	3.1	107.1	68.5	2185.2
2002/03	259	436.3	240.1	359.8	333.7	238.5	247.5	57	0	0	37.9	119.5	2329.3
2003/04	159.8	231.4	282.4	447.5	372.6	340.8	180.2	69.2	0	0.2	11.9	22.4	2118.4
2004/05	134.5	217.6	279.4	309.5	304.3	324.9	249.1	52.5	5.1	17.3	126.7	64	2084.9
2005/06	141.3	222.4	264.4	277	225	336.7	323	45.4	8.6	76.6	81.9	131.9	2134.2
2006/07	136	202.8	237.3	303.4	133.7	483.1	237.4	14.2	0	0	62.9	35.5	1846.3
2007/08	219.8	373.5	352.3	187.6	327.4	404	211	6.7	8.9	62.8	62.8	47.8	2387.2
2008/09	219.8	373.5	352.3	310.2	327.4	404	211	6.7	8.9	62.8	62.8	47.8	2387.2
2009/10	100.5	416.2	236	306.3	287.4	205.5	311.1	23.7	0	0	78.2	34.7	1999.6
2010/11	126	213.5	459	276.9	420.7	309.3	349.2	78.2	4.6	0	60.8	111.4	2409.6
2011/12	105.8	347.7	239.5	236.5	345.1	424.7	242.8	12	9.6	0	88.2	57	2108.9
2012/13	142	233.7	213	363	161.8	349	244.6	58.5	0	75.4	36.5	40.8	1917.3
2013/14	92.8	466.1	239.1	280.9	237.1	218	184.8	99.5	90.9	0	43.7	138.8	2191.6
2014/15	78.7	249.2	281.8	144.4	444.2	405.3	165.1	147.4	0	8.4	81.7	130.5	2136.7
Mean value	**144.21**	**293.55**	**297.77**	**289.38**	**296.91**	**336.96**	**252.46**	**58.06**	**10.43**	**17.15**	**59.21**	**89.81**	**2145.89**

Table 4. *Hydraulic Conductivity and Transmissivity values estimated from statistical grain size methods.*

Sample Location	Hydraulic conductivity cm/s			Transmissivity cm^2/s			Thickness (cm)
	Hazen (1983)	Harleman *et al.* (1963)	Uma *et al.* (1989)	Hazen (1983)	Harleman *et al.* (1963)	Uma *et al.* (1989)	
Isunabo	3.6×10^{2}	2.3×10^{2}	1.3×10^{1}	7.6×10^{4}	4.8×10^{4}	2.7×10^{3}	210
Umumara	3.6×10^{2}	2.3×10^{2}	1.3×10^{1}	7.2×10^{4}	4.6×10^{4}	2.6×10^{3}	200
Akpukpa	1.0×10^{-1}	6.4×10^{-2}	3.8×10^{-4}	1.0×10^{1}	6.4×10^{0}	3.8×10^{-2}	150
Nvurunvu	8.1×10^{0}	5.2×10^{0}	3.1×10^{-1}	8.9×10^{2}	5.7×10^{2}	3.4×10^{1}	200
Ndundu	4.0×10^{2}	2.5×10^{1}	1.5×10^{0}	5.2×10^{3}	3.3×10^{3}	2.0×10^{2}	130
Achara	6.4×10^{2}	4.1×10^{2}	2.4×10^{1}	1.5×10^{5}	9.4×10^{4}	5.5×10^{3}	230

Discussion of Results

Field results revealed that Uturu area is covered by sedimentary rocks. The sedimentary rocks of the area have under gone considerable weathering leading to about 50 – 150 meters thick unconsolidated weathered overburden layers consisting of loose sands, gravels, silts and clays.

- Plasticity index ranges from 19.00 to 27.00 indicating medium to slightly high plasticity.
- Optimum Moisture Content (OMC) rangers from 7.40% to 11.30%.
- Maximum Dry Density (MDD) ranges from 1.83 g/cm^3 to 2.12 g/cm^3.
- The grain size distributions ranges from 5.02 to 8.43
- Coefficient of uniformity ranges from 1.00 to 2.00
- Coefficient of curvature ranges from – 1.00 to 0.30
- The study area records 85% of the atmospheric precipitation (Obiefuna and Nur, 2003).
- A mean hydraulic conductivity, k is 5.02 m/s
- A mean transmissivity, T is 6.35 m^2/s

The incipient gullies were observed in different parts of Uturu and its environs, which are covered by the sedimentary rocks. The menace of devastation was found in four (4) locations.

The range of the depth of incision of the gullies observed is about 1.50m to 5.10 m with width ranging from 2.50m to 6.00 m (Table 1). The geotechnics of these areas determine the susceptibility to gully erosion or their erodibility. To determine the causes and to suggest solutions to the problems, the geotechnical parameters or characteristics of the soils at the seven (7) locations using soil mechanic laboratory test such as liquid limit and plastic limit, the grain size analysis, moisture content,

specific gravity and shear strength test were carried out. Table 2 summarizes the results of the test conducted. The liquid limit and plastic limits were used to obtain the plasticity index, which is a measure of the plasticity of the soil. The values obtained ranged from 19.00 to 27.00 indicating medium to slightly high plasticity according to Anon (1979). The samples are soft and could be crushed by fingers and hence erodible.

Compaction test indicates that the Optimum Moisture Content (OMC) ranges from 7.40% to 11.30% whereas the Maximum Dry Density (MDD) ranges from 1.83 g/cm^3 to 2.12 g/cm^3 indicating that the soils are slightly compacted and not loosed. The grain size distributions analysis indicate sorting values to range from 5.02 to 8.43 and coefficient of uniformity and coefficient of curvature values of 1.00 to 2.00 and -1.00 to 0.30 respectively indicating that the soils are fair to well sorted implying high content of the fine grained materials such as clays and silts that provide cohesion.

There are two marked seasons in the year: rainy (March – October) and dry (November – February) seasons. The hottest months are January – March with mean monthly temperature of 27^{o}Cc. Relative humidity is usually high throughout the year, reaching a maximum of 90% during the rainy season.

Benin Formation consists of thick unconsolidated sands with lignite streaks and wood fragments. The sands are sub-angular to well – rounded, most medium to coarse – grained, pebbly, and moderately sorted with inter-finger of local lenses of poorly cemented sands and clay, thus giving rise to multi-aquifer systems separated by aquitards.

The meteorological data from the Nigeria institute of meteorology, Umudike shown on Table 3 include the rainfall data for the study area. The average annual precipitation occurring almost entirely as rainfall over a sixteen water year period (April to March) amounted to 95,971,200 m^3 volume of water. The value of actual evapotranspiration estimated from Turc model based on the mean annual rainfall is about 83,726,749 m^3 or 85% of the atmospheric precipitation (Obiefuna and Nur, 2003). An estimate of the surface runoff of 18,545,899 m^3 or 19% of the atmospheric precipitation was achieved employing the Veisman (1972) rational formula. Thus based on Bell (1983), the infiltration was estimated by subtracting the sum of actual evapotranspiration and the surface runoff from the total precipitation. Accordingly, when this wasis done for the study area an average infiltration value of 65,180,850 m^3 was obtained.

The thick unconsolidated sand with lignite streaks and wood fragments gives rise to multi-aquifer systems. The unconsolidated weathered overburden aquifer is derived from the weathering of the underlying sedimentary rocks and consists of residual soils such as gravels, sands, silts and clays. The sediment aquifer directly underlies the unconsolidated weathered overburden aquifer and consists of sediments that have been subjected to weathering due to surface processes. Furthermore, while the hand- drug wells are tapping the unconsolidated weathered overburden aquifer, the boreholes are tapping the thicker and deeper part of the sedimentary aquifer unit.

The hydraulic properties as determined from statistical methods (Hazen, 1893; Harleman et al., 1963 and Uma et al., 1989) indicate a mean hydraulic conductivity K,

value of 5.02 m/s and a mean transmissivity, T, value of 6.35 m^2/s. Comparisons were made for K to the Todd (1995) and T to the Gheorghe (1978) classification and were found to be relatively high (Table 4).

Conclusion

The study has focused on the hydrogeological and geotechnical investigation of gully erosion sites in Uturu and its environs, Abia State, Nigeria. The study set out to answer few objectives which were: provide hydrogeological parameters and data of the area available in Uturu, Abia State; provide geotechnical parameter and data of the soils available in Uturu, Abia State; identified problems and features making the area susceptible to gully erosion; and proffer sustainable solutions to problems of gully erosion in the affected area of Uturu, Abia State.

Hydrogeological and geotechnical investigations of the sediments of Uturu and its environs were made for the purpose of inferring the surface and subsurface processes that contribute to the formation of gullies in the area. A mean hydraulic conductivity K and a mean transmissivity T values of 2.09 m/s and 3.79 m^2/s recorded indicate an aquifer unit of relatively high performance. The result of the geotechnical investigation indicate sorting values ranging from 0.42 to 2.3 and coefficient of uniformity and coefficient of curvature values of 3 to 10 and 0.2 to 1.3 respectively. Thus the soil is largely well sorted with high content of fine grain material such as silt and clays that provide cohesion. These made the soil loose and susceptible to gully erosion. The following are recommended control of gullies in the area:

- An integrated approach involving agronomic practices or massive afforestation efforts aimed at protecting the soil from direct impact of rain drops.
- Some engineering methods which can modify the slope characteristics in an attempt to check the amount and velocity of runoff (Obiefuna and Nur, 2003).
- Draining the soil using appropriate methods will help the shear strength and reduce the susceptibility of the soil to erosion.
- Continuous geotechnical evaluation should be carried on the soil to assess changes in the soil and the environment.
- Reclamation by back filling of existing gullies with laterite and other good filling materials accompanied by adequate compaction and drainage.
- The state government should enact an edict or law to prevent human activities such as burning, digging of sand and indiscriminate dumping of waste at erosion sites.

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Soil Carbon Forms and Organic Matter Distribution in Arable Soils of Rigachikun, Northern Kaduna, Nigeria

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Abstract

The study was done in Rigachikun Kaduna, Northern Guinea Savanna and intended to investigate the carbon forms such as Organic carbon, carbon loss on ignition (LOI), Biomass microbial carbon (BMC) as well as organic matter distribution of the studied soils. A reconnaissance survey was carried out in the study location using the developed Digital Elevation Model (DEM). Soils were delineated into mapping units using the cropping land uses namely maize, cowpea and rice. In each of the cropping land use, three profile pits were sited giving a total of nine profile pits. Organic carbon contents of investigated soils were low and decreased down the horizon in all investigated pedons. This trend follows closely to organic matter which decreased in the same pattern with the values of organic carbon. Carbon LOI had a very highly significant relationship with BMC and OM, non-significantly correlated with Carbon/Nitrogen ratio, Clay, pH, K, Na and total exchangeable acidity (TEA). Biomass carbon had a negative and significant correlation with organic carbon, very highly and significant correlation with organic matter. BMC tolled the path of LOI in its relationship with other soil properties investigated. Also, all carbon forms (LOI, BMC, OC and OM) investigated exhibited high (CV > 35%) coefficient of variation in all investigated locations except in pedon 3 of location B where BMC varied moderately and pedons 1 and 2 of Location C (Rice soils) where they all varied moderately (CV >15 ≤ 35%). Generally organic matter content of the soils was very low resulting from continual use of crop litters in the feeding of farm animals rather than incorporating them to the soils. Soil

degradation, erosion and desert encroachment have also affected soil of north western Nigeria so immensely.

Keywords: Organic carbon, organic matter, carbon loss on ignition, microbial biomass carbon

Introduction

Soil carbon is known to be the biggest stocks of terrestrial carbon (Batjes, 1996; Jobbagy and Jackson, 2000; Lal, 2004). Across the globe, soil has the largest carbon storage capacity when likened to the carbon pools in the vegetation or atmosphere. Soil carbon is likely the most significant factor in soils, exhibiting great effects on soil properties. Carbon in the form of soil organic matter alters the physicochemical as well as the biological properties of the soils (Rice 2005). Kome et al., (2021) posited that soil carbon is a major index of soil quality and productivity serving as major mover of most soil activities or functions. It encourages nutrient retention, formation of micro-aggregate and good soil structure, soil buffering capacity, activity of microbes, moisture retention and infiltration rate (Hartemink et al., 2014).

Adhikari and Hartemink (2016) outlined the cardinal services and roles played by soil carbon in the ecosystem to include; regulatory (e.g., carbon sequestration, climate and greenhouse gas regulations); provision of services (e.g., food, water, fuel, fiber), cultural services (e.g., ecotourism and recreation), and also supporting services such as nutrient cycling. Batjes (1996), noted that the top 1m of the soils across the globe harbors about 2200 Pg of C, with about 2/3 of it, amounting to 66%, stored as soil organic matter. This volume of C is almost thrice that obtained in the atmosphere. Generally, soil carbon stocks are regulated by the balance of C inputs from plant production and outputs through decomposition (Schlesinger, 1977). Meanwhile, human activities on the soil, mostly agricultural practices and forest clearance for fuel and timber, have resulted to the emission of huge amount of the stored carbon into the atmosphere (Lal, 2010).

On the other hand, some human activities can significantly increase soil carbon sequestration, which include; enhanced farming activities such as addition of biochar (Ouyang et al., 2014), incorporation of crop residues (Han et al., 2018), and conservation tillage (Olsen et al., 2013, Moussadek et al., 2014, Omara et al., 2019). Despite many anthropogenic activities, many biophysical factors affect soil carbon storage and its mode of distribution in the soil. Generally, soil carbon is available in three different forms, namely; passive, intermediate, and active (Xu et al., 2016). The active and intermediate fractions are found in the top 1 meter of soil and are often collectively known as labile (microbial biomass carbon) soil carbon (Trumbore 1997). The soil carbon available at this topmost surface of the soil is biologically available and more subjected to transformation at the soil surface (Cheng et al., 2015). The labile fraction is the smallest pool of soil carbon and is estimated at 250–350 Pg (Trumbore 1997). This fraction develops from dead decaying organisms and fresh organic residues with a turnover range of days to few decades. Also, the passive or

more dependable component of soil carbon (chemically stable in the form of humus) is often accumulated below 1 m and is not easily available to microorganisms for decomposition (Trumbore 1997).

The subsoil contains the highest volumes of soil carbon and is not easily affected by changes in management practice and different environmental conditions when compared to top soil (Xu et al., 2016; Rumpel and Kogel-Knabner 2011). Constant check and quantifying soil carbon contents across different soil units from time to time are vital for the appraisal of spatial and temporal variations in soil carbon pools and fluxes. This is most vital in accessing the changes in soil productivity and its fertility levels, soil deterioration/amelioration, water quality, environmental degradation, hence necessitating the adoption of sustainable soil management practices for enhancing soil carbon storage and increased ecosystem services (Adhikari et al., 2019).

SOC is the foundation for soil productivity and fertility, means by which microorganisms derive their energy and regulator of climate and biodiversity (Dou et al., 2016; Li et al., 2013). Knowledge of the potentials and behavior of soil carbon is not only important in enhancing soil quality and sustainability of rangelands in Sub-Saharan Africa, but also mitigate climate change by offsetting CO_2 emissions (Hafner et al., 2012). Soil organic carbon is seen as an indicator of soil quality as it determines soil structure, nutrient retention and supports biological diversity (Chazdon 2008; Gil-Sotres et al., 2005). The reduction or loss of SOC could, therefore, lower soil fertility and consequently, lead to land degradation (Rounsevell et al., 1999). Today, it is absolutely necessary to give adequate attention to a better management of soil organic carbon to enhance soil fertility and productivity. As has been emphasized elsewhere, farmers and producers of tomorrow may need to not only farm soil judiciously but to also “farm carbon” (Lal, 2008). This study investigated different carbon forms and organic matter in arable soils of Rigachikun, Northern Guinea Savanna, Nigeria.

Materials and Methods

Location

The study area is located on the Latitudes 10^o 36’ and 10° 60’ N and Longitudes 7^{o}25’ and 7° 40’E respectively and in the north western Nigeria**.** Uyovbisere and Lombin (1991) noted that this region has a unimodal rainfall pattern and between 900 – 1300 mm per annum. The region also has a rolling but relatively plain slopes, having most of its elevations between 500 to 700 m, occupied by majorly sandy soils, which are critical in organic matter contents, degrading highly especially under intense precipitation and overgrazing (Obasi et al., 2022). The region experiences high intermediate annual temperature (28-32°C), brief rainy period and long dry season lasting from 6-9 months. The soil moisture and temperature regimes in the area are inferred to be ustic and isohyperthemic respectively (Soil Survey Staff 1975). Mean temperature often drops to 25^{o}C – 28^{o}C (June to September) usually during the rains and decreases to less than 20^{o}C in the months between December and February (Gabasawa et al., 2017). Vegetation ranged from woodland to light forest which has been reduced to bare land due to uncontrolled tree felling for fuel as well as farming

activities (Carsky et al., 1998) while abundant short grasses (<2 m) are also available attracting nomadic cattle grazing (Sowunmi and Akintola, 2010).

Table 1. *Geographic Coordinates of Research area in Rigachikun, Kaduna*

Land Use	Location	Longitude	Latitude	Altitude (m)
Maize	1	10.614447	7.475940	609
	2	10.614585	7.476755	609
	3	10.613689	7.478127	605
Cowpea	1	10.614625	7.478230	607
	2	10.615250	7.477857	611
	3	10.716818	7.477228	610
Rice	1	10.615858	7.476001	612
	2	10.615727	7.475068	615
	3	10.613786	7.475203	609

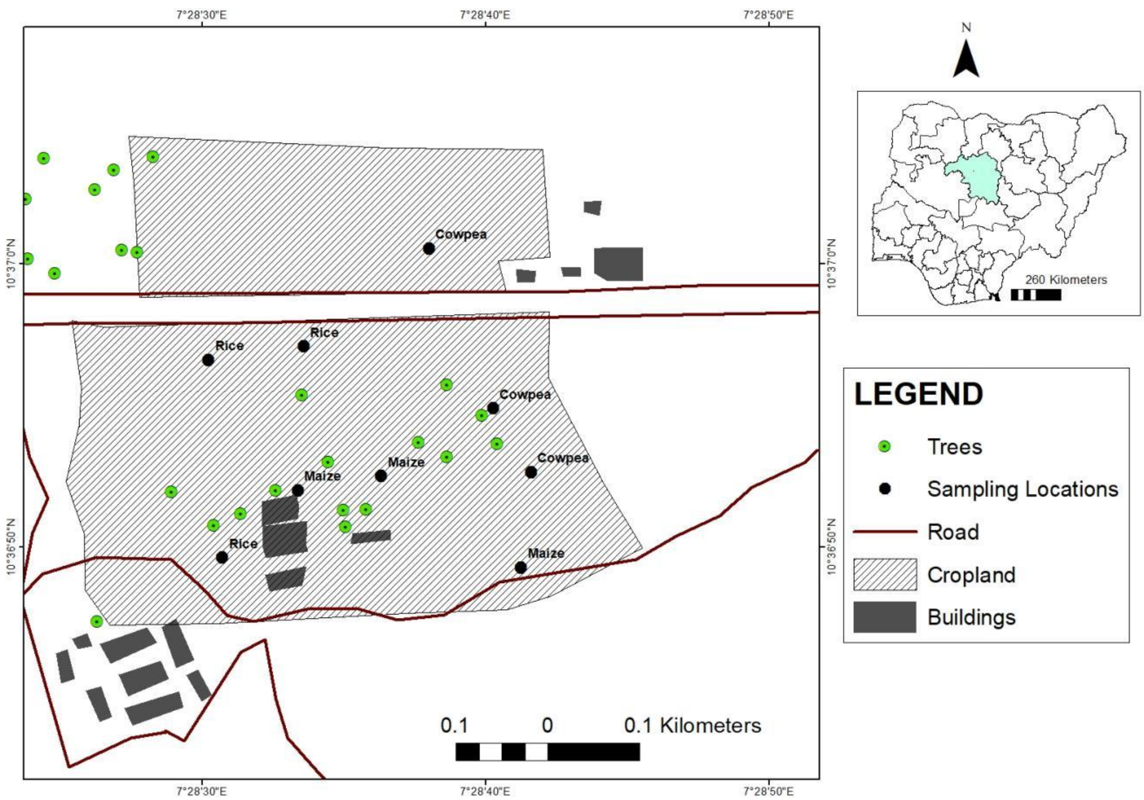

Fig. 1. *Map of study area showing sampling points*

Existing Information on Soil

United States Department of Agriculture soil classification system placed soils of Northern Nigeria as Aridisols (Soil Survey Staff 1975). The soils of this region displays the properties of arid lands having very retarded moisture movement in the soil and slowly permeable, while greater volumes of its rains get lost through run-off (Fitzpatrick, 1980). These soils may have originated intense dry condition from wind-stored desert sands that accumulated over a long period of time. Also, some soils in the Northern Guinea Savanna found in states like; Kaduna, Katsina, Kebbi, Sokoto

and Zamfara of Northern Nigeria have been known to be ferruginous tropical soils (D'Hoore, 1965) and having mostly sandy texture, stretching through huge areas of land with minimal water-holding capacity and critical organic matter, nitrogen and phosphorus content, neutral or moderately acidic in pH and also having a low cation exchange capacity (Obasi et al., 2022). The region has the potentials to support mostly grain crops like maize, sorghum, millet, rice and wheat in the vast land mass that dominated the northern guinea savanna soils (Shehu et al., 2015).

Vegetation

Rigachikun is located in north western Nigerian with a vegetation of tropical Guinea Savanna. The increased anthropogenic influences such as nomadic cattle grazing, bush burning, and intense farming have apparently transformed the huge part of the original vegetation to bare lands (Obasi et al., 2022). Fitzpatrick (1980) stated that such vegetation of arid soils are always scantily distributed causing its surface to lay bare for long periods. Consequently, severe soil degradation situations arising from mostly wind erosion, leading to decline in soil fertility, and other serious soil and environmental degradation problems. However, few shrubs and grasslands are still available. The region has been occupied by some grasses such as; Elephant grass *(Pennisetum purpurem)*, Giant star grass *(Cynodon plectostachyus)*, Wild groundnut *(Calopogonium mucunoides)*, butterfly pea *(Centrosema pubescens)*, Goat weed *(Sida acuta*)(Obasi et al., 2022)

Socioeconomic Activities

Cereals are the most important stable food crop in this region (Muhamman and Gungula, 2006), grown by the people of Rigachikum whose major occupation is subsistence farming with food crops farming commonly practiced. Harris (2000) accounted that "In sub-Sahelian northern Nigeria, farmers mostly grow millet, sorghum, groundnut, sesame and cowpea and in the Sahelian part they fall back to highly drought-tolerant crops such as millet and cowpea". Meanwhile, the most marginal crops among them are sorghum and millet (both early and late varieties). Aregheore, (2005) reported that the most dominant crops grown by farmers in many northwestern states such as; Katsina, Kano, Kaduna, Sokoto and Zamfara are millet, sorghum, maize, cowpea, groundnut, and sometime soybean. Cereals are usually the dominantly farmed crops with one or few other crops mixtures. The cropping mixtures mostly practiced in the location may be; sorghum/groundnut; sorghum/cowpea; sorghum/millet/ cowpea and sorghum/millet (Muhamman and Gungula, 2006). Furthermore, millet and sorghum are usually planted on the same plot in most farmlands around Kano, Kebbi and Sokoto states. Millet are usually planted immediately after the first rain, while sorghum is inter-planted later after the rain must have become more intense and reliable (Mortimore, 1989). Asadu et al, (2004) stated that crops such as cowpea which covers the soil well may be brought into different cropping system such as crop rotation and mixed cropping.

Field Work

A reconnaissance survey was carried out in the study location using the developed Digital Elevation Model (DEM). Soils were delineated into mapping units using the cropping land uses namely maize, cowpea and rice. Three profile pits were dug in each cropping land use of maize, rice and cowpea depending on the identified soil groups, pedons were sunk in each of the delineated mapping units giving a total of nine profile pits. About 1kg samples were collected from the different horizons of each pedon at the different arable crop grown soils for carbon content and organic matter analysis as well as other soil physicochemical properties studied. Samples were carefully packaged and labeled and transported to the standard Soil Science laboratory of ABU, Zaria for analysis.

Laboratory Soil Analysis

Some physical and chemical properties of the soil were used as parameters for the study. Physical properties are: Mechanical analysis (particle size distribution), while the chemical properties are: soil pH, exchangeable acidity (Al^{3+} and H^{+}), exchangeable bases (Ca^{2+} , Mg^{2+},K^{+}, Na^{+}), ECEC, percentage base saturation, total nitrogen, available phosphorus, organic carbon, organic matter and carbon /nitrogen ratio. Their methods of determination are as follow: Particle size distribution was determined by hydrometer method using the procedure of (Gee and Or, 2002), Soil pH was determined in 1:2.5 soil liquid ratios in water and 0.1N KCl (IITA, 1979). Organic Carbon was determined using method described by (Nelson and Sommers, 1996). Total Nitrogen was determined using modified micro Kjeldahl method (Bremner and Milvaney 1982); Total available phosphorus was determined using Bray II method (Olsen and Sommers, 1982); Cation exchange capacity (CEC) was measured by repeated saturation using 1M NH_4OAC followed by washing, distilling and titrating (Soil Survey Staff, 1996). LOI was measured using the method of Schulte and Hopkins (1996). Biomass carbon was estimated using the method of Marumoto (1984).

Digital Elevation Model (DEM) Study

A digital elevation model (DEM) is a digital representation showing ground surface topography or terrain, mostly referred to as a digital terrain model (DTM). In this research, the DEM was derived from the contour lines of the topographic map of the study areas. Global Positioning System was used for ground truthing of the study area for recording of coordinates of the crop lands used for the study. Digital Elevation Model (DEM) was generated using a point data having the x, y, z coordinates arranged in a regular grid pattern. Furthermore, the point data grids were imported into surfer 21.0 software to produce the 3 Dimensional digital elevation model (Acker et al, 2003). Digital elevation model (DEM) is used by most GIS professionals to extract topographic information such as slope and aspect. With the DEM data for the study area, a grid file is generated in ArcView first, and then a slope file. The points of regular grids were now used to generate the Digital Elevation Model using Kriging interpolation Method (Pavlova, 2017). Coordinates readings

were thereafter launched to ArcGIS 10.5 platform and later linked with Google Earth for full identification of the crop land and its environs.

Statistical analysis

Coefficient of Variation (CV) was used to estimate the degree of variability existing among soil properties in the study site. Coefficient of variation (C.V.) ranked as follows; Low variation ≤15%, Moderate variation >15≤35%, High variation >35% was used as outlined by Wilding, (1985). Correlation was done using SPSS software package.

Result and Discussion

Organic Carbon and Carbon Loss on Ignition (LOI)

Soil organic carbon (SOC) and carbon loss on ignition (LOI) of the studied soil are as shown in (Table 3). Organic carbon content of investigated soils were low and means recorded as follow; location A; 3.142, 3.193 and 2.926 gkg^{-1}; location B, 2.044, 2.493 and 3.940 gkg^{-1}, location C, 3.460, 3.940 and 3.03 gkg^{-1} in their pedons 1, 2 and 3 respectively. The organic carbon all decreased down the horizon in all investigated pedons. This trend follows closely to organic matter which decreased in the same pattern with the values of organic carbon. Organic matter distribution took the following trends; Location A; 5.525, 5.505 and 5.044 gkg^{-1}; Location B; 3.525, 4.300 and 6.793 gkg^{-1}. Location C; 5.960, 6.800 and 5.221 gkg^{-1} all in their respective pedons 1, 2 and 3. The high concentration of organic substances such as twigs, litter, dead decayed organisms on the surface of soils may be largely responsible for the higher organic carbon and organic matter on or near the surface of the studied soils. (SOM) has been used in different ways to describe the organic constituents of soil (Obasi et al., 2015; Obasi et al., 2019). Carbon loss on ignition (LOI) were highest at the surface horizons and decreased down the profile steadily in all investigated soils. Means Carbon loss on ignition were as follow; location A; 1.053, 1.064 and 0.990 gkg^{-1}; B; 0.712, 0.830 and 1.249 gkg^{-1}; C; 1.070, 1.320 and 0.812 g/kg in their pedons 1, 2 and 3 respectively. There was high variability (CV > 35) carbon loss in all investigated pedons of all locations except in location C pedons 1 and 2 where it was moderate (CV > 15 ≤ 35).

Carbon LOI correlated highly significantly with BMC and Organic matter. It however has a negative and non-significant correlation with organic carbon, Avail. P, Ca, Mg and total exchangeable bases (TEB). Batti and Bauer (2002) noted that LOI method measures the organic-matter content of soils, but the change of the organic-matter content to a C basis may be tasking because the C content of organic matter may not be compatible and varies with vegetation type, degree of decomposition, age, and other factors. Thus, direct correlation between LOI and total C may be necessary for each soil type, geographic region, or land management practice (Konen et al. 2002). Previous researches indicated that LOI was a good predictor of total C, but with field verification necessary to optimize the conversion factors (Batti and Bauer 2002). Wright et al., (2008) used LOI method to assess total C in wetland soils of the Everglades. Soil total C measurement undertaken by Carbon-Nitrogen-Sulphur

analysis was confounded by the presence of $CaCO_3$, which exists in Everglades soils at widely variable concentrations. The LOI method was not impaired by $CaCO_3$ at any organic-matter content. The relationship between soil total C and LOI was excellent in soils with organic matter levels exceeding 400 g/kg. The present study scored OM values < 10 g/kg in all study locations and may be responsible for the negative and non-significant relationship between organic carbon and carbon LOI.

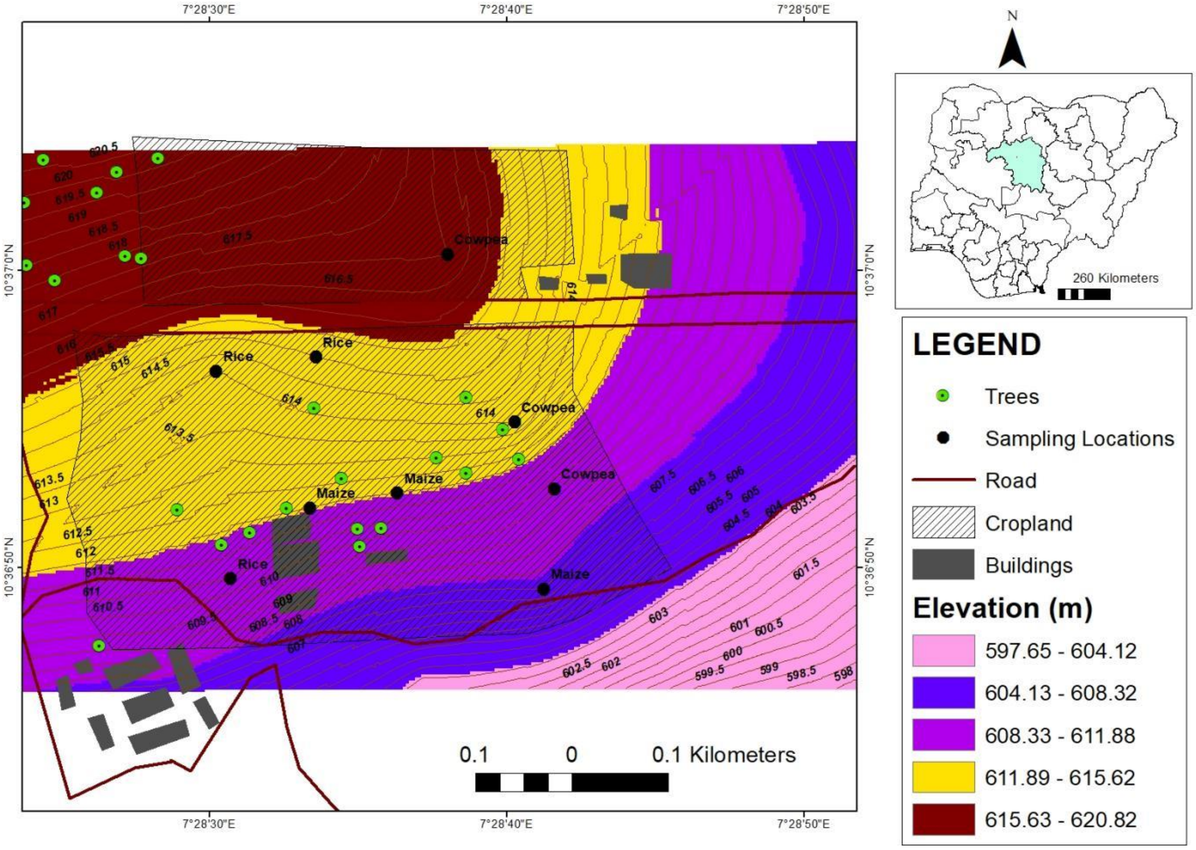

Fig. 2. *Map of Study Area Showing Sampling Points and Contour Lines*

Table 2. *Means of selected soil properties*

Locations	Clay	pH	Organic M.	Avail. P	K	Na	Ca	Mg	TEB	TEA
	gkg^{-1}		gkg^{-1}	$mgkg^{-1}$			gkg^{-1}			
Maize	102.5	5.97	3.525	2.83	0.08	0.03	5.80	1.59	7.48	0.95
	102.5	6.05	4.300	2.58	0.08	0.05	4.35	1.18	5.66	0.85
	137.5	5.88	6.793	1.63	0.06	0.05	4.25	1.25	5.61	0.85
Cowpea	90	6.04	5.96	2.32	0.06	0.06	4.20	1.24	5.56	1.20
	82.5	6.00	6.80	2.02	0.10	0.11	5.45	1.51	7.17	1.12

	110	6.07	5.221	2.02	0.14	0.15	3.65	1.03	4.97	1.05
Rice	107.5	6.51	5.418	1.89	0.29	0.21	6.20	1.67	7.66	0.8
	80	6.27	5.503	2.19	0.14	0.09	6.05	1.68	7.96	1.45
	80	6.14	5.044	2.86	0.11	0.05	7.53	2.03	9.73	0.67

Table 3. *Soil Carbon Distribution of Studied Soils in gkg^{-1}, BMC (mgCkg^{-1})*

Samples locations	LOI	BMC	OC	CNR	OM	LOI	BMC	OC	CNR	OM	LOI	BMC	OC	CNR	OM
	Pedon 1					**Pedon 2**					**Pedon 3**				
Location A: Maize															
A	2.340	8.729	6.983	7.98	12.04	2.594	8.650	7.781	7.99	13.41	1.729	5.760	5.187	8.00	8.942
AB	0.931	3.491	2.793	7.36	4.815	0.865	3.240	2.594	6.99	4.472	0.700	2.490	1.995	7.00	3.439
Bt1	0.670	2.217	1.995	7.00	3.439	0.466	1.750	1.397	7.02	2.408	0.540	2.000	1.596	7.00	2.752
Bt2	0.270	1.000	0.798	7.00	1.376	0.332	1.250	0.998	6.97	1.721	-	-	-	-	-
Mean	1.053	3.359	3.142	7.34	5.418	1.064	3.722	3.193	7.24	5.503	0.990	3.41	2.926	7.33	5.044
CV	85.51	88.15	85.56		85.57	98.16	91.12	98.14	-	98.12	65.20	115.9	67.27		67.26
Location B: Cowpea															
A	1.950	6.210	5.586	8.00	9.630	1.529	5.740	4.589	7.00	7.911	3.200	12.00	9.576	8.00	16.51
AB	0.532	1.770	1.596	7.98	2.752	0.930	3.100	2.793	7.34	4.815	0.798	3.550	3.192	7.00	5.503
Bt1	0.266	1.000	0.798	7.00	1.376	0.530	2.000	1.596	8.02	2.752	0.598	2.250	1.796	7.02	3.096
Bt2	0.103	0.250	0.199	7.11	0.343	0.332	1.250	0.998	6.98	1.721	0.400	1.490	1.197	7.00	2.064
Mean	0.712	2.308	2,044	7.52	3.525	0.830	3.140	2.493	7.33	4.300	1.249	4.823	3.940	7.26	6.793
CV	118.14	100.8	118.8		118.8	63.60	21.85	63.49	-	63.48	104.9	29.16	97.68		97.68
Location C: Rice															
A	1.463	4.870	4.389	7.99	7.567	1.610	5.300	4.772	8.01	8.227	1.652	7.340	6.607	7.01	11.39
AB	1.000	4.430	3.990	8.18	6.879	1.530	5.090	4.589	7.99	7.911	0.734	3.260	2.937	8.00	5.063
Bt1	0.837	3.140	2.512	7.00	4.331	1.468	4.890	4.405	8.01	7.594	0.551	2.070	1.652	7.00	2.848
Bt2	0.980	3.260	2.937	7.01	5.063	0.673	2.520	2.019	7.01	3.481	0.310	1.150	0.918	6.90	1.583
Mean	1.070	3.925	3.46	7.54	5.96	1.320	4.45	3.946	7.76	6.80	0.812	3.46	3.029	7.48	5.221
CV	25.41	24.55	25.42		25.42	32.98	30.35	32.78	-	32.78	72.25	67.23	83.45		83.45

LOI = Carbon Loss on Ignition, BMC = Soil Biomass Carbon, OC= Organic Carbon, CNR = CN Ratio, OM = Organic Matter

Soil Organic Matter

Organic matter took after the organic carbon trend as it decreased in the same pattern with the values of organic carbon. Organic matter distribution took the following trends; Location A; 5.525, 5.505 and 5.044 gkg^{-1}; Location B; 3.525, 4.300 and 6.793 gkg^{-1}. Location C; 5.960, 6.80 and 5.221 gkg^{-1} all in their respective pedons 1, 2 and 3. The high concentration of organic substances such as twigs, litter, dead decayed organisms on the surface of soils may be largely responsible for the higher organic carbon and organic matter on or near the surface of the studied soils. (SOM) has been used in different ways to describe the organic constituents of soil. Baldock and Skjemstad (1999) stated that SOM includes “all organic materials found in soils irrespective of origin or state of decomposition”. SOM consists of C, H, O, N, P and S. Included are living organic matter (plants, microbial biomass and faunal biomass),

dissolved organic matter, particulate organic matter, humus and inert or highly carbonized organic matter. Part of soil organic matter consists of carbohydrates, lipids and proteins that are abundant in fresh plant residues. These are rapidly metabolized, immobilized or decomposed (Adiaha, 2017). Lombin et al., (1991) noted that although there is a considerable variation in the nutrient composition of organic manures depending mainly upon the source, handling and management, the main nutrients supplied are N, P, K, Mg, Ca and a host of micro nutrients. The organic matter contents of locations A and B where rice and cowpea were previously grown were higher than those of Location B where maize was harvested although these differences does not entail much variation from the results. The huge litter deposits from rice husks and cowpea leaves may have contributed to these relatively higher values.

Adiaha (2017) reported that when organic matter is added to the soils, it does not only tackle bulk density challenges and increase water holding capacity of the soil, but also adequately enhance soil aggregate stability. Ander and Carter (1996) discovered that the quantity of water – stable aggregate (WSA) was usually a function of organic carbon content, and that labile carbon was usually positively correlated to macro-aggregate stability. Kay and Anger (1999) reported that a minimum of 2% SOM was necessary to maintain structural stability. Boix-Fayos et al., (2001) noted that a threshold limit of 3-3.5% SOM had to be reached to achieve increase in aggregate stability. However, all investigated pedons in the studied location all had their organic matter content far below the minimum organic matter requirement of soils as suggested by Kay and Anger (1999) and Boix-Fayos et al., (2001), who gave 2% and 3-3.5% (equivalent to 20 gkg^{-1} and 30 – 35 gkg^{-1}) suggesting that organic matter will possibly pose serious challenge to the productivity of the studied soils acting as a limiting factor in the nutritional composition of the soils. Nguemezi et al., (2020) who worked on South-west Cameroun soils noted that any soil with organic matter content of < 2% will definitely encounter limitation challenge to soil productivity. The low organic matter in these soils may be linked to continual use of rice husks and other plant litters in the feeding of cattle and other farm animals which is a common practice in most parts of northern Nigeria. These crop residues, if they had been allowed to decompose on the soils, could have added substantial amount of organic matter to the soils. All the investigated locations showed high variability (CV ≥ 35) except pedons 1 and 2 of location C where coefficient of variation was moderate (CV > 15 < 35) according to Wilding (1985).

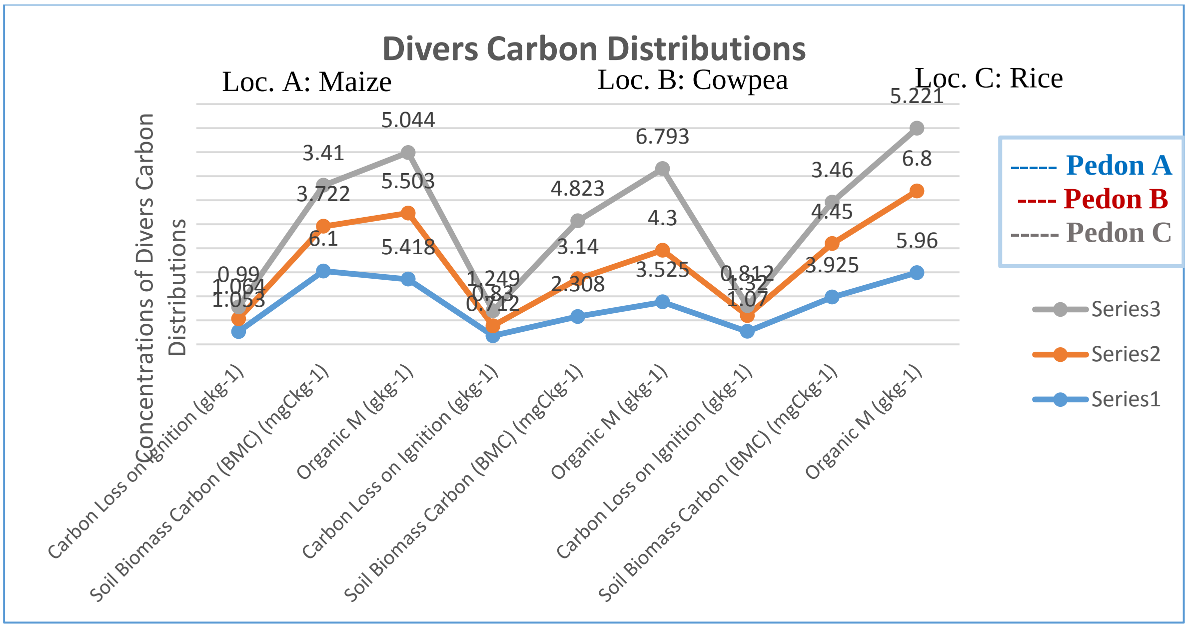

Fig. 3. *Relationship between divers Carbon Contents of Soil*

Soil Biomass Carbon

Soil Biomass Carbon took the trend of organic matter and organic carbon in pattern of distribution across horizons (table 3; fig. 3). They were highest at the surface and decreased down the profile. The means distribution of biomass carbon follows thus; Location A; 6.10, 3.722 and 3.41 mg Ckg^{-1}; location B; 2.308, 3.140 and 4.823 mg C/kg; location C; 3.925, 4.45 and 3.46 mg C kg^{-1} in pedons 1, 2 and 3 of the respective locations. There was high variability (CV > 35) in virtually all the investigated soils except location B pedons 2 and 3 and location C pedons 1 and 2 where soil biomass carbon had moderate variability (CV >15 ≤ 35). More biomass were produced in Maize Plot pedon 1(6.10 mg C kg^{-1}), followed by Rice Plot pedon 3 (4.823 mg C kg^{-1}) and Cowpea Plot pedon 2 (4.45 mg C kg^{-1}) while lowest occurred in Rice Plot pedon 1 (2.308 mg C kg^{-1}). The high variability of BMC in soil across crop utilization types could be attributed to differences in biomass production which influences mineralization, because it is accessible to micro-organisms. The rate of organic carbon input from plant biomass is generally considered a dominant factor controlling amount of microbial biomass present in the soil (Campbell *et al.*, 2000; Omeke *et al.*, 2016). Adeboye (2009) opined that BMC values are commonly high when large amounts of organic C are returned to the soil. Therefore, continuous and uniform supply of C from crop residues with low C/N ratio like cowpea would serve as an energy source for microbial activity in the soil (Omeke et al., 2016). To a large extent, this would also contribute to soil productivity improvement. Omeke et al., (2016) described soil microbial biomass as the living part of soil organic matter and composes less than 10 percent organic matter content in soil. However, it performs at least three important functions for plant production in an ecosystem; namely, labile source and sink of C, N, P and S, agent of nutrient transformation and pesticide degradation and acts as a cementing agent, promoting soil aggregation and structure (Salinas-Garcia et al., 2002). Due to its dynamic character, microbial biomass

responds faster to changes in soil management, often before measurable changes occur in organic C and N (Carter and Rennie, 1982). A challenge in interpreting values of microbial biomass is the difficulty of knowing the attainable microbial biomass for a given land use and what level of microbial biomass may constrain production.

Table 4. *Correlation of Carbon Forms with Soil selected Soil Properties*

	LOI	BMC	OC	CNR	OM	Clay	pH	Avail. P
LOI	1,000							
BMC	0,906	1,000						
OC	-0,558	-0,669	1,000					
CNR	0,140	0,051	0,219	1,000				
OM	0,937	0,972	-0,657	0,163	1,000			
Clay	0,208	0,129	-0,185	-0,487	0,117	1,000		
pH	0,313	0,386	-0,126	0,623	0,445	-0,278	1,000	
Aval. P	-0,206	-0,201	0,053	-0,022	-0,090	-0,530	-0,100	1,000

Correlation Study of Soils

Carbon LOI had a very highly significant relationship with BMC and OM, non-significantly correlated with Carbon/Nitrogen ratio, Clay, pH, K, Na and total exchangeable acidity (TEA). It maintained a negative and non-significant correlation with organic carbon, Ca, Mg and total exchangeable bases (TEB). Biomass carbon had a negative and significant correlation with organic carbon, very highly and significant correlation with organic matter. BMC tolled the path of LOI in its relationship with other soil properties investigated. Organic carbon had a negative significant correlation with organic matter. It equally maintained a negative non-significant relationship with virtually all other properties investigated, except Avail. P and TEA where it had a positive and non-significant relationship. Organic matter correlated positively but non-significantly with other soil properties such as clay, Ca, Na, pH, TEB and TEA except Avail. P where it had a negative non-significant relationship.

Conclusions

Organic carbon content of investigated soils was low and means recorded as follow; location A; 3.142, 3.193 and 2.926 gkg^{-1}; location B, 2.044, 2.493 and 3.940 gkg^{-1}, location C, 3.460, 3.940 and 3.03 gkg^{-1} in their pedons 1, 2 and 3 respectively. The organic carbon all decreased down the horizon in all investigated pedons. This trend follows closely to organic matter which decreased in the same pattern with the values of organic carbon. Carbon LOI had a very highly significant relationship with BMC and OM, non-significantly correlated with Carbon/Nitrogen ratio, Clay, pH, K, Na and total exchangeable acidity (TEA). Biomass carbon had a negative and significant correlation with organic carbon, very highly and significant correlation with organic matter. BMC tolled the path of LOI in its relationship with other soil properties investigated. This study has established that organic matter and organic

carbon content of soils of Rigachikun fall far below the threshold levels expected in most tropical soils. The causes of organic matter decline may be linked to environmental problems such as soil erosion and desertification as well as human activities such as overgrazing and bush burning. The situation has greatly threatened sustained agricultural productivity in many States of northern Nigeria including Adamawa, Bauchi, Borno, Gombe, Jigawa, Kaduna Kano, Katsina, Kebbi, Sokoto and Zamfara. These problems have led to serious damage to farmlands by the loss of organic matter, and the deterioration of soil structure which have significantly decreased crop yield in successive years.

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Impact of the different sources of mulch on soil chemical properties of an Ultisol in Umudike, South East Nigeria

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Abstract

This research was conducted at the Teaching and Research Farm of Abia State University Umudike, to evaluate the impact of different sources of mulch on soil chemical properties of an Ultisol in Umudike, South East Nigeria. The experiment comprised of five (5) treatments namely, Control = 0t/ha, R1 – Ricemill waste 10/ha, R2 - Ricemill waste 15/ha, S1 - Sawdust =10t/ha, S2 - Sawdust = 15t/ha. The experiment was laid out in a Randomized Complete Block Design (RCBD) with the treatments replicated three (3) times to give a total of fifteen (15) plots. Raw data obtained was analyzed using analysis of variance (ANOVA) and significant means were separated using Fisher least significant difference (F-LSD) at probability level of ($P<0.05$). The results obtained showed that total exchangeable acidity significantly ($P<0.05$) reduced in mulched plots compared to the control. Soil pH, available phosphorous, total nitrogen, organic carbon and exchangeable cations of mulched plots were significantly ($P<0.05$) higher than the control. Similarly, Effective cation exchange capacity (ECEC), percentage base saturation and C: N ratio was significantly ($P<0.05$) higher when compared with the control. Sawdust application at the rate of 15t/ha significantly ($P<0.05$) increased pH, organic carbon, available phosphorous, effective cation exchange capacity (ECEC), percentage base saturation and C: N ratio compared to control and ricemill at 15t/ha. However, Ricemill waste at 10t/ha and 15t/ha significantly ($P<0.05$) increased soil total nitrogen and sodium (Na) content compared to control and sawdust at different rates. Ricemill waste and sawdust mulch positively influenced soil chemical properties and could be recommended for enhancement of soil chemical properties in Umudike South East Nigeia.

Key words: Impact, Mulch, Ricemill, Sawdust, Soil Properties.

Introduction

Soil fertility maintenance is a major concern in the tropics, particularly in this South-East Agro ecological zone of Nigeria. The rapid depletion of nutrients and poor physical condition of the soil are strong limitation to crop production (Okonkwo *et al*., 2011). Tropical soils are beset with problems of high acidity, acute nutrient deficiency and soil erosion (Ekpe, 2008). They are equally low in cation exchange capacity (CEC) with little or no mineral reserve, low water holding capacity and low soil pH. Due to high cost and scarcity of chemical fertilizer, it has become necessary to source for agro industrial wastes which could be used as manure for crops in tropical countries. Recently research focused on the potential of these organic materials as soil improvers and sources of nutrients. The waste which has been proved as effective organic fertilizers include animal waste, wood ash, rice husk, sawdust, and other crop waste (Awodun, 2007). Organic mulching with different materials such as rice husk, sawdust, groundnut shell, grasses etc, when correctly applied on the soil surface as shades serves as barrier against moisture losses from the soil, causing slow surface run-off, mitigate soil temperature, increase soil water content which contribute to better long term growth by improving the organic matter content and releasing minerals into the soil (Salahudeen and Sadeer, 2018).

Mulching is an agricultural technique that uses organic materials (sawdust, straw, leaves ricehusk etc) and synthetic materials to improve soil productivity (Paunovic et al., 2020). Mulching is used to retain moisture in the soil, modify soil temperature, supply nutrients, improve soil structure and control weeds (Pandey *et al*., 2016). Research has shown that organic mulch provides many benefits to crop production through soil and water conservation enhance soil biological activity and improve chemical and physical properties of soil (Esther *et al*., 2019). However, the utilization of these organic wastes such as ricemill waste and sawdust by farmers is still poor despite the nutrient composition of these materials (Wuese *et al*., 2018). The relative neglect of these wastes as soil amendments has partially been attributed to their bulkiness, low nutrient quality and high C: N ratio. Based on this, the best approach in the utilization of these waste is converting them to ashes or complementing them with high nitrogen source materials to increase their mineralization process (Wuese *et al*., 2018).

Agricultural waste such as ricemill waste and sawdust is important for its value as fertilizer as well as its ability to improve soil physic-chemical properties (Herath *et al*., 2013). The potential of organic waste such as ricemill waste and sawdust in improving soil physio-chemical properties has been reported in many studies (Lu *et al.,* 2014). Jien and Wang, 2013 reported an increase in soil pH, exchangeable potassium, calcium, magnesium and cation exchange capacity (CEC) due to application of ricemill waste to the soil. Also Vidana *et al*., (2016) reported an increase in soil physio-chemical properties due to application of ricehusk to the soil. Shu-aib *et al*., (2020) reported an increase in soil physical and chemical properties of soil due to application of ricehusk and sawdust to the soil. Application of industrial waste has become popular in agriculture because of its benefits in improving soil properties and association with its high organic matter content. Few information

regarding the use of organic waste such as ricemill waste and sawdust as mulch is limited in South East Nigeria. This research was therefore aimed at assessing the impact of different sources of mulch on soil chemical properties of an Ultisol in Umudike South East Nigeria.

Materials and Method

Site Description

The study was carried out at the teaching and research farm of Abia State University Umudike. The study site was situated on latitude $5^0 25'$ N and Longitude $7^0 35'$ E in the rain forest ecological zone of South East Nigeria at an altitude of about 122m above sea level (Uche, 2006). The study site had a humid tropical climate, annual temperature of $27\text{-}29^0$ and annual rainfall of 2.500mm which runs from March to December with its peak in July. The dry season last from December to March with a dry dust and cold intervals. The soil of the study area is classified as Ultisols using the USDA soil classification and Acrisol. Ultisols, are highly acidic, coarse textured and highly leached upland soils. The major vegetation found in the experimental site is the secondary forest which represents what was left of the tropical rain forest. Some species found are oil palm (*Elaeis guinensis*), *Alchomea cordifolia* and *Maniophytum fuluvm*. The dominant grasses include *Panicum maximum*, *Pennisetum purpereum* while *Cetrocema pubecece* are the dominant shrubs. Sweet potatoes, pepper and vegetables such as okra and fluted pumpkin are some of the crops commonly planted either on mounds, ridges or flats.

Site Preparation

A total land area of $240m^2$ (20×12) was used for the study. The experimental site was mechanically ploughed and harrowed. Measuring tapes, pegs and ropes were used in mapping out the treatment plots. Fifteen experimental plots measuring 3m×3m were used for the experiment. Each plot was separated by 1m to prevent treatments from interfering with each other.

Experimental Materials and Treatments Allocation

Sawdust was collected from Umuahia Central Timber Market and ricemill waste was collected from the ricemill industry at Bende Local Government Area in Abia state Nigeria. The test crop telfairia seeds were obtained from National Rootcrops Research Institute Umudike. The telfairia seeds were planted two weeks before treatments application. The treatments and their respective rates are 0 – Control, Ricemill Waste (R1) –10t/ha, Ricemill Waste (R2) –15t/ha, Sawdust (S1) – 10t/ha and Sawdust (S2) –15t/ha.

Experimental Design/Field Layout

The experiment was laid out in a randomized complete block design (RCBD) with treatments replicated three times as shown in figure 1.

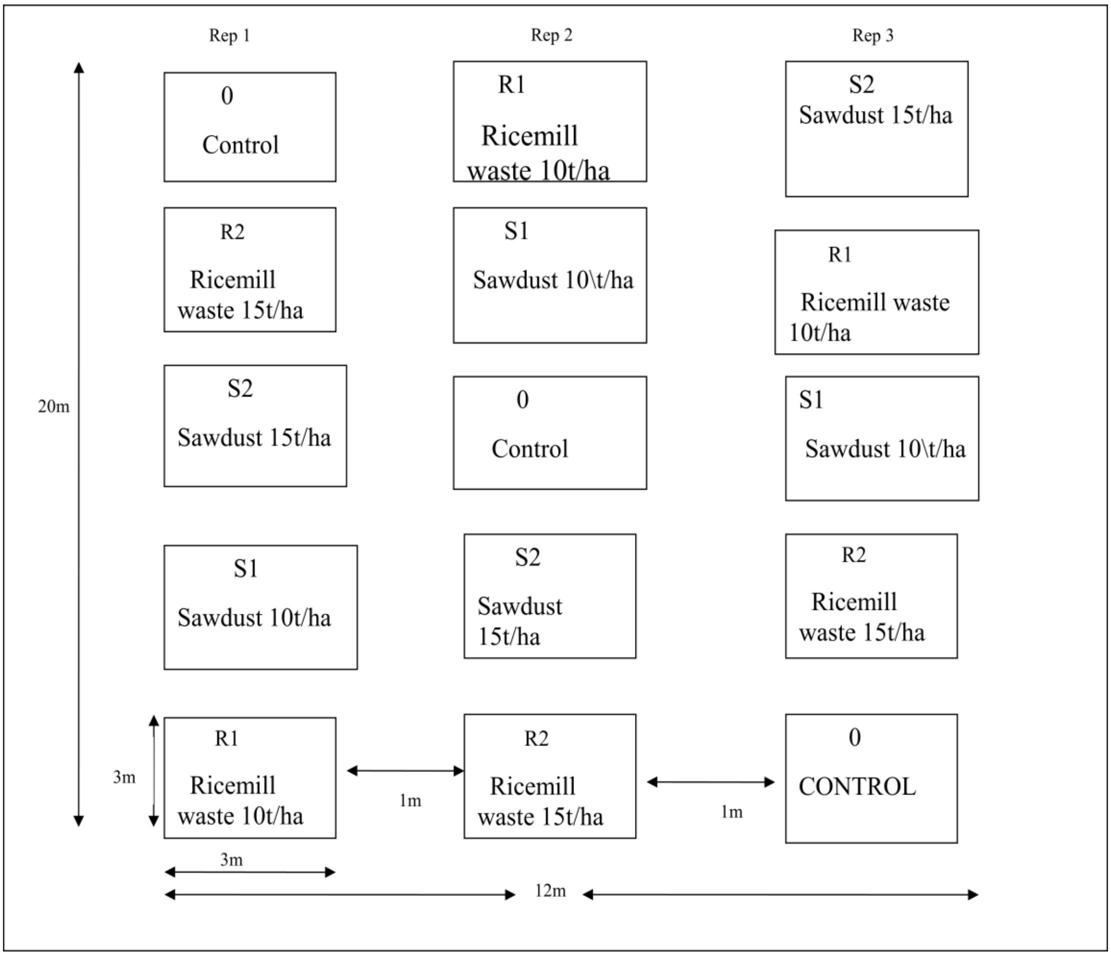

Figure 1. *Field layout of the Experimental Site*

Data Collection

Soil samples were collected with soil augar at 0-20 cm soil depth across the field for routine analysis. All collected samples were air dried, crushed and sieved using 2mm sieve in preparatory for chemical properties determination.

Laboratory Analysis

The laboratory soil analysis was carried out at Soil Science Laboratory of National Rootcrops Research Institute Umudike and the following soil properties were determined;

Soil Chemical Properties

Organic carbon was determined by the Walkley and Black (1934) wet-oxidation method as modified and described in manual of soil, plant and water analysis (Eno *et al*.,2009). Available phosphorous was determined by Bray and Kurtz No.2 (1945) method adopted by Juo (1979) in which the phosphorous was extracted with 1ml NH_4F and 0.5ml Hydrochloric acid. Colour development was achieved by adding "reagent B". Available phosphorous was determined calorimetrically using a photo calorimeter. Total nitrogen was determined by micro Kjeldahl digestion and distillation method of Bremner (1965) as recently modified and described in the manual of soil and water analysis (Eno *et al*., 2009) using concentrated H_2SO_4 and a

sodium copper sulphate catalyst mixture. Soil pH was determined in the laboratory with a glass pH meter at a ratio of 1:2.5 water ratios. Exchangeable cations (Ca, Mg, Na and K) were extracted with ammonium acetate solution. Exchangeable calcium and magnesium was determined by the ethylene diaminetetracetic acid titration method as described by Black (1965), whereas exchangeable potassium and sodium were determined by flame photometry method. Exchangeable acidity (EA) was determined by the titrimetric method Bray and Weit (1999). Total exchangeable acidity (TEA) was determined by the summation of H^+ and Al^{3+}.

$$TEA = (H^+ + Al^{3+})$$

Equation (1)

Effective Cation Exchange Capacity was determined by the summation of exchangeable acidity (Al^{3+} and H^+) and exchangeable bases).

$$ECEC = (Al^{3+} \text{ and } H^+) + (Ca^{2+}, Mg^{2+}, Na^+ \text{ and } K^+)$$

Equation (2)

Percentage base saturation was calculated by the summation of the total exchangeable bases divided by effective cation exchange capacity and then multiplied by 100.

$$\% BS = \frac{TEB}{ECEC} \times 100$$

Equation (3)

Statistical Analysis

Data generated were subjected Analysis of variance (ANOVA) based on the procedure outlined by Gomez and Gomez (1984). Means were separated using Fisher least significant difference (F-LSD) at a probability level of 5%.

Result and Discussion

Chemical Properties of the Experimental Site before the application of Mulch Materials.

Table 1. *Chemical Properties of the Soil of the Experimental Site*

Soil Parameters/Minerals	Values
pH in H_2O (1:2:5)	5.07
Organic Carbon (%)	0.47
Total Nitrogen (%)	0.12
Available phosphorous (mg/kg)	21.0
Calcium (Ca) (Cmol/kg)	1.33
Magnesium (Mg) (Cmol/kg)	0.10
Potassium (K) (Cmol/kg)	0.83
Sodium (Na) (Cmol/kg)	0.07
Exchangeale Acidity(Cmol/kg)	1.40
ECEC (Cmol/kg)	3.73

The chemical properties of soil of the experimental site is shown in Table 1, the result showed that the soil is acidic with pH vale of 5.07, organic carbon content and total nitrogen were both low with values of 0.47% and 0.12% respectively. Available phosphorus was high with value of 21mg/kg. Exchangeable cations, Ca, Mg, K, and Na were also low, with calcium having the highest value of 1.33 and sodium the lowest value of 0.07 Cmol/kg. ECEC was also low with value of 3.733Cmol/kg, while exchangeable acidity 1.40 Cmol/kg. The low ECEC could be explained by the low soil organic matter content and the highly weathered and leached nature of the soil.

The Nutrient Composition of Sawdust and Ricemill Waste used for the study.

The chemical properties of sawdust and ricemill waste used for the study are shown in Table 2.

Table 2. *Nutrient Composition of Sawdust and Ricemill Waste used for the study*

Properties	Sawdust	Ricemill Waste
Organic Carbon (%)	5.20	12.32
Total Nitrogen (%)	0.28	0.93
Available phosphorous (mg/kg)	0.15	0.83
Calcium (Ca) (mg/100g)	0.70	0.60
Magnesium (Mg) (mg/100g)	0.18	0.12
Potassium (K) (mg/100g)	0.28	0.18
Sodium (Na) (mg/100g)	0.08	0.06
C: N Ratio	18.57	13.24

The analytical result of the nutrient composition of ricemill waste and sawdust used for the study is shown in Table 2. The result showed that ricemill waste was high in carbon, moderate in total nitrogen and low in phosphorus with values of 12.32% ,0.93% and 0.83(mg/kg) respectively. While calcium, magnesium, potassium ad sodium were also low with values of 0.60, 0.12, 0.18, and 0.06 Cmol/kg respectively. Similarly the result also showed that sawdust was also high in carbon and magnesium content with values of 5.20% and 0.18 (mg/100g) respectively, while total nitrogen, available phosphorous and sodium content was low with ~~w~~values of 0.28%, 0.15(mg/kg) and 0.08 (mg/100g) respectively.

Effect of Ricemill Waste and Sawdust on Soil Chemical Properties

The result of the effect of ricemill waste and sawdust is shown in Table 3

Soil PH$_w$

The result of the effect of mulching the soil with ricemill waste and sawdust on soil pH$_w$ showed that relative to the control, application of ricemill waste at 10t/ha and 15t/ha significantly ($p<0.005$) increased soil pH$_w$ with values of 1.06 and 1.33 pH$_w$ respectively. Similarly application of sawdust at the rate of at 10t/ha and 15t/ha increased soil pH$_w$ significantly ($p<0.005$) relative to the control with 2.05 and 2.43 pH$_w$ respectively. Also when sawdust at 10t/ha and 15t/ha was compared with ricemill waste at 10t/ha and 15t/ha, sawdust recorded 0.99 and 1.10 higher in soil pH$_w$

compared to 10t/ha and 15t/ha of ricemill waste application. Thus sawdust application at 15t/ha recorded the highest significant ($p<0.005$) increase in soil pH_w compared to other mulched plots. These observed increases in soil pH_w as a result of mulching with these materials could be attributed to the supply of calcium ions by the wastes and this is in agreement with the observations of Njoke *et al.,* (2007). Paunovic *et al*., (2020) noted an increase in soil pH due to application of organic waste.

Table 3. *Effect of Ricemill Waste and Sawdust on Soil Chemical Properties*

TRET	$P^{H}w$	OC (%)	T N (%)	AVP (mg/k)	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	EA	ECEC	C:N	BS (%)
					→ Cmol/kg ←							
0	4.50^{a}	0.50^{a}	0.06^{a}	28.44^{a}	1.20^{a}	1.23^{a}	0.05^{a}	0.16^{a}	2.10^{e}	4.74^{a}	8.33^{a}	55.69^{a}
R1	5.56^{b}	2.10^{b}	0.22^{d}	39.55^{b}	2.00^{b}	1.83^{b}	0.13^{b}	1.18^{c}	1.42^{b}	6.56^{b}	9.54^{b}	78.35^{b}
R2	5.83^{c}	2.98^{c}	0.18^{c}	40.72^{c}	2.19^{b}	1.99^{b}	0.15^{b}	1.23^{c}	1.23^{a}	6.79^{c}	16.55^{c}	81.88^{c}
S1	6.55^{d}	2.20^{b}	0.12^{b}	56.70^{d}	2.33^{b}	3.70^{c}	0.83^{c}	1.10^{b}	1.75^{d}	9.71^{d}	18.33^{d}	81.97^{c}
S2	6.93^{e}	3.22^{d}	0.16^{b}	64.30^{e}	2.50^{b}	4.30^{d}	0.86^{c}	1.04^{b}	1.65^{c}	10.35^{e}	20.13^{e}	84.05^{ds}
F-LSD P =0.05	0.13	0.14	0.05	1.36	0.62	0.48	0.07	0.12	0.005	0.17	0.81	0.82

Legend: *0 =Control, R1 = Ricemill Waste 10t/ha, R2 = Ricemill Waste at 15t/ha, S1 = Sawdust at 10t/ha, S2 = Sawdust at 15t/ha, OC = Organic carbon, TN = Total Nitrogen, AVP = Available phosphorous, Ca = Calcium, Mg = Magnesium, K = Potassium, Na = Sodium, EA = Exchangeable Acidity, ECEC = Effective Cation Exchange Capacity, C: N= Carbon to nitrogen ratio, BS = Base Saturation.*

Note: *Figures with the same superscript are not statistically significant.*

Organic Carbon (%)

The result of the effect of mulching the soil with ricemill waste and sawdust on soil organic carbon showed that relative to the control, application of ricemill waste at 10t/ha and 15t/ha significantly ($p<0.005$) increased soil organic carbon with values of 1.60 and 2.48% respectively. Similarly application of sawdust at the rate of at 10t/ha and 15t/ha increased soil organic carbon significantly ($p<0.005$) relative to the control with 1.70 and 2.72% respectively. Also when sawdust at 10t/ha and 15t/ha was compared with ricemill waste at 10t/ha and 15t/ha, there was no significant ($p<0.005$) difference when plot mulched with sawdust at 10t/ha was compared with plots mulched with ricemill waste at 10t/ha. However, sawdust application at 15t/ha recorded 0.24% higher organic carbon compared with ricemill waste at 15t/ha. The observed increases in the organic carbon of the mulched plots relative to the control could be explained in terms of the nature of the mulch materials which are high in carbon content probably due to the age of the material. This increase in soil organic carbon by addition of organic mulches has been reported by Ojikpong and Michael Kekong, (2019).

Total Nitrogen (%)

The result of the effect of mulching the soil with ricemill waste and sawdust on total nitrogen showed that relative to the control (0.06)%, total nitrogen increased significantly ($p<0.005$) with increasing rate of ricemill waste application. The application of ricemill waste at 10t/ha and 15t/ha significantly ($p<0.005$) increased

total nitrogen with values of 0.12 and 0.16% respectively compared with the control. Similarly application of sawdust at the rate of 10t/ha and 15t/ha increased total nitrogen significantly ($p<0.005$) relative to the control with values of 0.06 and 0.10 %respectively. Also when sawdust at 10t/ha and 15t/ha was compared with ricemill waste at 10t/ha and 15t/ha, sawdust recorded 0.10 and 0.02 % lower in total nitrogen compared to 10t/ha and 15t/ha of ricemill waste application respectively. However, application of ricemill wastes at 10t/ha and 15t/ha particularly at 15t/ha recorded the highest significant ($p<0.005$) increase in soil total nitrogen. The observed increases in soil total nitrogen of the mulched plots relative to the control could be due to the mineralization of nitrogen from the decomposing mulch material. The superiority of ricemill waste over sawdust could be explained by the wider C: N ratio of sawdust.

Available Phosphorous (mg/kg)

The result of the effect of mulching the soil with ricemill waste and sawdust on soil available phosphorous showed that relative to the control, application of ricemill waste at 10t/ha and 15t/ha significantly ($p<0.005$) increased soil available phosphorous with values of 11.11 and 12.28 Mg/kg respectively. Similarly application of sawdust at the rate of at 10t/ha and 15t/ha increased soil available phosphorous significantly ($p<0.005$) relative to the control with 28.26 and 35.86 Mg/kg respectively. Also when sawdust at 10t/ha and 15t/ha was compared with ricemill waste at 10t/ha and 15t/ha, sawdust recorded 17.15 and 23.58 Mg/kg higher in soil available phosphorous compared to 10t/ha and 15t/ha of ricemill waste application respectively. Thus sawdust application at 15t/ha recorded the highest significant ($p<0.005$) increase in both rates. These observed increases in soil available phosphorous as a result of mulching with these materials could be due to the increase in soil pH that can unlock fixed P in acidic soils and this is in line with the findings of Abdulaziz Alharbi,(2017).

Calcium, (Ca)

The result of the effect of mulching the soil with ricemill waste and sawdust on calcium showed that relative to the control, application of ricemill waste at 10t/ha and 15t/ha significantly ($p<0.005$) increased calcium content with values of 0.80 and 0.99 Cmol/kg respectively. Similarly application of sawdust at the rate of at 10t/ha and 15t/ha increased the calcium content significantly ($p<0.005$) relative to the control with value of 1.13 and 1.30 Cmol/kg respectively. Also when sawdust at 10t/ha and 15t/ha was compared with ricemill waste at 10t/ha and 15t/ha, there was no significant ($p<0.005$) difference recorded among the different rates of sawdust used and the different rates of ricemill waste used rather their values varies. The observed increases in the exchangeable cations (Ca, Mg, K and Na) as a result of mulching with these materials could be attributed to the high level of organic carbon in the waste. Similar results were documented by Ayeni, (2010) and Ojikpong and Michael Kekong,(2019)

Magnesium (Mg)

The result of the effect of mulching the soil with ricemill waste and sawdust waste on magnesium content showed that relative to the control, application of ricemill waste at 10t/ha and 15t/ha significantly ($p<0.005$) increased the soil magnesium content with values of 0.60 and 0.76 Cmol/kg respectively. Similarly

application of sawdust at the rate of at 10t/ha and 15t/ha increased soil magnesium content significantly ($p<0.005$) relative to the control with values of 2.47 and 3.07 Cmol/kg respectively. Also when sawdust at 10t/ha and 15t/ha was compared with ricemill waste at 10t/ha and 15t/ha, sawdust recorded 1.87 and 1.99 Cmol/kg higher in soil magnesium content compared to 10t/ha and 15t/ha of ricemill waste application. Thus sawdust application at 15t/ha recorded the highest significant ($p<0.005$) increase compared to sawdust at 10t/ha and ricemill waste at 10t/ha and 15t/ha. This confirms the report of Udom *et al*, (2017) who noted that application of organic manure to the soil increase ca^{2+}, Mg,$^{2+}$ k^{+}, and Na in the soil.

Potassium (K)

The result of the effect of mulching the soil with ricemill waste and sawdust on the potassium content showed that relative to the control, application of ricemill waste at 10t/ha and 15t/ha significantly ($p<0.005$) increased soil potassium content with values of 0.08 and 0.10 Cmol/kg respectively. Similarly application of sawdust at the rate of at 10t/ha and 15t/ha increased soil potassium content significantly ($p<0.005$) relative to the control with values of 0.78 and 0.81 Cmol/kg respectively. Also when sawdust at 10t/ha and 15t/ha was compared with ricemill waste at 10t/ha and 15t/ha, sawdust recorded 0.70 and 0.71 Cmol/kg higher in soil potassium content compared to 10t/ha and 15t/ha of ricemill waste application. However, there was no observed significant difference between sawdust at 10t/ha and 15t/ha. Thus sawdust application at 15t/ha recorded the highest significant ($p<0.005$) increase in soil potassium content compared to other mulched plots. This agrees with the result of Agbede and Adekiya, (2016) who reported increase in soil potassium with the application of organic waste.

Sodium (Na)

The result of the effect of mulching the soil with ricemill waste and sawdust on sodium content showed that relative to the control, application of ricemill waste at 10t/ha and 15t/ha significantly ($p<0.005$) increased soil sodium content with values of 1.02 and 1.07 Cmol/kg respectively. Similarly application of sawdust at the rate of at 10t/ha and 15t/ha increased the sodium content significantly ($p<0.005$) relative to the control with values of 0.94 and 0.88 Cmol/kg respectively. Also when sawdust at 10t/ha and 15t/ha was compared with ricemill waste at 10t/ha and 15t/ha, sawdust at 10t/ha and 15t/ha recorded 0.08 and 0.19 Cmol/kg lower in soil sodium content compared to application of ricemill waste at 10t/ha and 15t/ha. However, there was no significant ($p<0.005$) difference observed between 10t/ha and 15t/ha of ricemill waste application and 10t/ha and 15t/ha of sawdust application. Although application of ricemill waste at 15t/ha recorded the highest increase in sodium contents.

Exchangeable Acidity (EA)

The result of the effect of mulching the soil with ricemill waste and sawdust on exchangeable acidity showed that relative to the control, application of ricemill waste at 10t/ha and 15t/ha significantly ($p<0.005$) reduced the exchangeable acidity with values of 0.68 and 0.87 Cmol/kg respectively. Similarly application of sawdust at the rate of 10t/ha and 15t/ha reduced soil exchangeable acidity significantly ($p<0.005$) relative to the control with values of 0.35 and 0.45 Cmol/kg respectively.

Also when sawdust at 10t/ha and 15t/ha was compared with ricemill waste at 10t/ha and 15t/ha, sawdust at 10t/ha ad 15t/ha reduced exchangeable acidity significantly ($p<0.005$) with values of 0.33 and 0.42 Cmol/kg compared to ricemill waste at 10t/ha and 15t/ha. However, ricemill waste at 15t/ha recorded the highest significant ($p<0.005$) reduction in soil exchangeable acidity compared to other mulched plots. These reductions observed in the mulched plots could be attributed to the increased exchangeable cations contained in the mulching material. There are also reports of increased basic cations in the soil and reduction in soil acidity due to ricehusk and sawdust applicaton. (Njoke and Mbah., (2012) and Azu *et al*.,2021).

Effective Cation Exchange Capacity (ECEC)

The result of the effect of mulching the soil with ricemill waste and sawdust on soil effective cation exchange capacity (ECEC) showed that relative to the control, application of ricemill waste at 10t/ha and 15t/ha significantly ($p<0.005$) increased soil effective cation exchange capacity (ECEC) with values of 1.82 and 2.05 Cmol/kg respectively. Similarly application of sawdust at the rate of at 10t/ha and 15t/ha increased soil effective cation exchange capacity (ECEC) significantly ($p<0.005$) relative to the control with values of 4.97 and 5.61 Cmol/kg respectively. Also when sawdust at 10t/ha and 15t/ha was compared with ricemill waste at 10t/ha and 15t/ha, sawdust recorded 3.15 and 3.38 Cmol/kg higher in soil effective cation exchange capacity (ECEC) compared to 10t/ha and 15t/ha of ricemill waste application respectively. Thus sawdust application at 15t/ha recorded the highest significant ($p<0.005$) increase in soil effective cation exchange capacity (ECEC) compared to other mulched plots. Similar results were supported by Amenkhienan et al.,(2019).

C:N Ratio

The result of the effect of mulching the soil with ricemill waste and sawdust on C: N ratio showed that relative to the control, application of ricemill waste at 10t/ha and 15t/ha significantly ($p<0.005$) increased soil C: N ratio with values of 1.21 and 8 .22 respectively. Similarly application of sawdust at the rate of at 10t/ha and 15t/ha increased soil C: N ratio significantly ($p<0.005$) relative to the control with values of 10.00 and 11.80 respectively. Also when sawdust at 10t/ha and 15t/ha was compared with ricemill waste at 10t/ha and 15t/ha, sawdust recorded 8.79 and 3.58 higher C: N ratio compared to 10t/ha and 15t/ha of ricemill waste application respectively. Thus sawdust application at 15t/ha recorded the highest C: N ratio compared to other treated plots. However, plots which received sawdust mulch at various rates were higher than plots that received ricemill waste at various rates; this indicates predominance of immobilization over mineralization. According to Havlin *et al*., (2006) a C: N ratio of about 10 is considered a satisfactory condition for normal microbial activities in humus decomposition and a C: N ratio of above 20 indicates the predominance of immobilization process over mineralization resulting in the release of little nitrogen into the soil.

Percentage Base Saturation

The result of the effect of mulching the soil with ricemill waste and sawdust on Percentage Base Saturation showed that relative to the control, application of ricemill waste at 10t/ha and 15t/ha significantly ($p<0.005$) increased the percentage base

saturation with values of 22.66 and 26.19(%) respectively. Similarly application of sawdust at the rate of at 10t/ha and 15t/ha increased the soil percentage base saturation significantly ($p<0.005$) relative to the control with values of 26.28 and 28.36(%) respectively. Also when sawdust at 10t/ha and 15t/ha was compared with ricemill waste at 10t/ha and 15t/ha, sawdust recorded 3.62 and 2.17(%) higher in soil percentage base saturation compared to 10t/ha and 15t/ha of ricemill waste application respectively. However, there was no significant ($p<0.005$) difference observed when 15t/ha of ricemill waste application was compared with 10t/ha of sawdust application. Thus sawdust application at 15t/ha recorded the highest significant ($p<0.005$) increase in soil percentage base saturation compared to other mulched plots. Sabir and Zia (2015) reported similar result that soil ECEC and percentage base saturation increased with the addition of organic waste to the soil.

Conclusion

The result of this study showed that ricemill waste and sawdust applied at different rates (10t/ha and 15t/ha) improved soil organic carbon content, total nitrogen, soil pH, exchangeable cations and base saturation in the soil when compared with the control. Mulching the soil with ricemill waste (10t/ha and 15t/ha) and sawdust (10t/ha and 15t/ha) reduced the acidity of the soil because of its contributions to the exchangeable cations in the soil. Increase in available phosphorous and ECEC was observed with increase in the rate of mulch applied. Application of sawdust at 15t/ha was more significant in improving the soil chemical properties in Umudike South East Nigeria.

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Comparative Analysis of Growth of Seedlings from Half-sibs Progenies of Selected Robinia pseudoacacia L. Clones

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Abstract

An assessment of the growth of one-year-old seedlings from six selected *Robinia pseudoacacia* L. clones on the territory of the nursery "Lokorsko" of State Forest Enterprise Sofia was made. The results show differences in quantitative parameters of growth of black locust seedlings in two variants of experiment – seed rows and containers. This suggest a correlation between the seed provenance and the growth of seedlings, which are probably genetically justified. Clones Appalachia, Jaszkiseri и Riyhovo-7 are most suitable for production of black locust seedlings based on their quantitative parameters with good seed germination and established sowing rates.

Key words: black locust, clone, half-sib progeny, seedlings, growth

Introduction

Black locust (*Robinia pseudoacacia* L.), which is multipurpose tree species, is assessed lately worldwide as one of the perspective species for production of biomass and energy plantations grown at higher density and short rotation (Gyuleva et al., 2013; Gyuleva, 2014; Geyer, 2006; Rédei et al., 2010, 2011, Stankova et al., 2016; 2018; 2020).

To increase the productivity and quality of the wood, plantations are already being established from selected (seed and vegetative) planting material. Hungary is a leader in the improvement of black locust, with the first best clones of growth and productivity, and stem quality described by Keresztesi (1988). As a result of new improvement programme at the beginning of the XXI century, 12 clones of black locust were selected, recommended for afforestation by Rédei et al. (2002) and Rédei (2003).

The first black locust seed orchards in Bulgaria have been established in the 1980s, which has put the black locust management on a scientific basis (Donchev, 1989). Along with the development and improvement of a technology for vegetative propagation of the species with root cuttings (Naydenov et al., 1989; Broshtilov et al., 1998), the clonal frame for this species was introduced. Tsanov et al. (1992) publish

the first results from testing the vegetative progenies of 34 selected black locust clones from 6 populations in North Bulgaria.

From the established plantations and orchards, forest reproductive material is obtained today, from which seedlings with valuable qualities are produced for the needs of forestry.

The aim of the present study is a comparative analysis of the growth of seedlings from half-sibs progenies of six selected *Robinia pseudoacacia* L. clones with a view to their future use for the needs of forestry.

Materials and Methods

Objects of investigation are seeds from six selected *Robinia pseudoacacia* L. clones, collected from vegetative seed orchard of State Forest Enterprise Parvomay next to Mechka reka nursery. The orchard was established in 2004 at a scheme 8x8 m and includes 37 clones. For the control, a total collection of seeds is used with provenance from vegetative seed orchard located in the forest nursery Lukovit (State Forest Enterprise Lesidren).

To test the qualities of the half-sibs progenies of the six selected *Robinia pseudoacacia* L. clones, an experiment was set up in the forest nursery Lokorsko (State Forest Enterprise Sofia). It was carried out in two variants – on seed rows and containers for production of seedlings of deciduous species. The containers have 28 nests, in which 10 seeds from clone are sown according to relevant scheme. The seed rows are 7 with a length of 1 m and a distance of 10 cm between the rows, in which seeds are sown according to the scheme of each clone. The experiment was performed in three replications for each of the variants (Figure 1).Pre-sowing preparation of the black locust seeds was made after the method of three times dipping in boiling water followed by cooling. This method has been recommended as efficient and safe (Stefanov, 1951; Mirzaei et al., 2013; Basbag et al., 2010; Abdullah et al., 2019; Christin et al., 2019). With the aim of better scarification, ice has been added to the cooling water.

The sowing was carried out on 15 May 2021. The sowing rate is determined according to the formula from Annex 7 of Ordinance 4/15.02.2012 on the terms and conditions for registration of forest nurseries, as well as for the production of seedlings in forest nurseries – state property.

$$D = 10 * O * M / C * Gs * K$$, where

D – density of the sowing – in g/m
O – optimal number of germinated seedlings per 1 m (number of one year-old seedlings according to Annex 7 of the Ordinance № 4.+20%reserve for waste)
Gs – germination of seeds from the batch in %
M – mass of 1000 seeds from the batch in g
C – purity of the seeds in %
K – correction factor for soil germination of seeds (<1, established experimentally)

Sowing norms for each seed lot in table 1 are determined during investigation of the sowing qualities of the seeds of studied black locust clones (Dimitrova, Stoyanov, 2022).

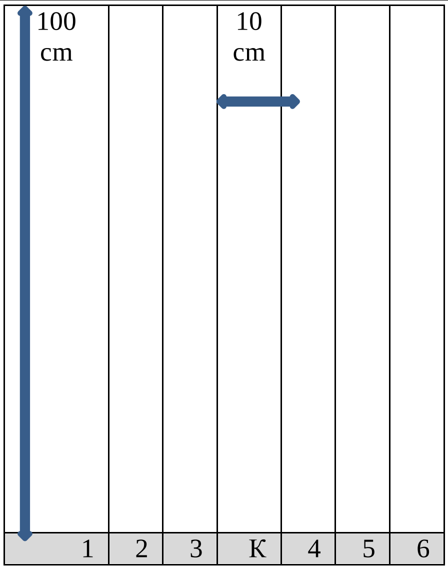
Table 1. *Values for sowing density for Robinia pseudoacacia L. clones*

Clone from *Robinia pseudoacacia* L.	Location (forest enterprise)	Laboratory germination %	Soil germination %	Sowing norm g/m	Sown / Germinated seeds
Pordim – 4	Plovdiv/ Parvomay	31	24	1.63	131 / 32
Jaszkiseri	Plovdiv/ Parvomay	59	52	0.85	65 / 33
Oryahovo – 5	Plovdiv/ Parvomay	21	16	2.12	224 / 35
Pordim – 1	Plovdiv/ Parvomay	7	5	8.25	579 / 30
Ryahovo – 7	Plovdiv/ Parvomay	15	11	3.51	206 / 31
Appalachia	Plovdiv/ Parvomay	38	31	1.39	98 / 31
Control	**Lukovit**	52	45	0.96	71 / 32

Sowing in both variants of experiment was made in a universal substrate with the following characteristics: medium fraction (0 - 40 mm), composition (in 250 l scale: 70 % bright peat 0 - 40 mm, 30 % black peat 0 - 40 mm, 1 kg NPK 14-16-18, 50 g trace elements and Tenzid – moisturising agent, pH 5,5 - 6,5. In each row are left 30 seedlings, and in the case of containers 2 seedlings are left in the nest. The seedlings are grown outdoors, with regular watering and weeding until the end of the growing season (31 October 2021).

The reports on the results of seedlings growth from half-sibs progenies of the six *Robinia pseudoacacia* L. clones were carried out monthly until the end of growing season (October 31, 2021). The height, diameter of the root collar and the length of the root of one-year-old seedlings were measured. Data were statistically processed using one-way Anova analysis of variance and Dunkan’s criterion for comparing mean values (Snedecor, W.G., W.G. Cochran, 1989).

6	**5**	**4**	**3**	**К**	**2**	**1**
К	**1**	**2**	**3**	**4**	**5**	**6**
6	**5**	**4**	**3**	**К**	**2**	**1**
1	**2**	**3**	**4**	**5**	**К**	**6**



A **B**

Legend: 1 – clone Pordim 4; 2 – clone Jaszkiseri; 3 – clone Oryahovo 5; 4 – clone Appalachia; 5 – clone Pordim 1; 6 – clone Ryahovo 7; К – control

Figure 1. *Scheme of sowing seeds of Robinia pseudoacacia L. in containers (A) and seed rows (B)*

Results and Discussion

The analysis of the data in table 2 shows differences in the quantitative parameters of black locust seedlings in both variances of the experiment. With regard to the average height of the seedlings, it is higher in the variant seed rows 33.5±9.7 cm compared to that of the container seedlings of 15.8±2,2 cm. This is the trend for the average values of the root length of 16.6± 3.7 cm for seed rows seedlings and 12.7± 0.9 cm for those in containers. The diameter of the root collar has an average value of 4.5 ±1.5 mm for variant seed rows and 4.4± 0.9 mm for the container variant.

Table 2. *Quantitative parameters of one-year old seedlings from half-sibs progenies of selected Robinia pseudoacacia L. clones*

Clone		Quantitative parameters														
		Seed rows							Containers							
	L/H %	Length of root (cm)	Height of seedlings (cm)			Diameter of the root collar (mm)			Diameter of the root collar (mm			Height of seedlings (cm			Length of root (cm)	L/H %
		L_{av}	H_{min}	H_{max}	H_{av}	D_{min}	D_{max}	D_{av}	D_{min}	D_{max}	D_{av}	H_{min}	H_{max}	H_{av}	L_{av}	
Pordim - 4	47.0	12.4	21	39	26.4	0,2	0.6	0.3	0.3	0.5	0.4	13	22	16.3	12.5	76.6
Jaszkiseri	44.4	15.9	28	46	35.8	0.3	0.8	0.5	0.3	0.7	0.4	14	21	17.1	13.6	79.5
Oryahovo– 5	54.1	18.3	25	44	33.8	0.3	0.8	0.5	0.3	0,5	0.5	14	17	15.7	12.5	79.6
Pordim – 1	63.3	13.3	17	25	21.0	0.2	0.5	0.3	0.3	0.6	0.4	13	18	15.6	12.2	78.2
Ryahovo – 7	42.3	18.9	25	57	44.6	0.2	1.0	0.5	0.3	0.6	0.4	13	17	16.4	12.5	76.2
Appalachia	46.0	18.4	26	57	40.0	0.3	0.8	0.4	0.3	0.6	0.5	14	19	16.6	12.4	74.6
Control	51.5	17.1	25	44	33.2	0.3	0.8	0.5	0.3	0.6	0.4	14	18	15.4	11.8	76.6
Total		16.6			33.6			0.4			0.4			15.8	12.7	

Legend: H – mean height of seedlings; L – mean length of root

The progenies of Ryahovo - 7, Appalachia and Jaszkiseri clones are characterized by the highest height, diameter of root collar and root length of the seedlings for the seed rows variant. In the case of containers seedlings, the progenies of the same clones have the best parameters in the following order - Jaszkiseri, Appalachia and Ryahovo – 7. One-year old seedlings have a well-developed root system, the length of which is from 42.3 to 63.3% of the height of the seedlings from the seed rows and 74.6 to 79.5% in the container variant.

The applied multi-rank Duncan criterion identified well-defined and statistically significant differences in the mean values of the studied quantitative parameters of seedlings between the clones in both variants of the experiment (Table 3).

Differences between the growth parameters of the clones have been proven in the research of Tsanov et al. (1992), who tested the vegetative progenies of 34 clones of 6 populations of black locust in Northern Bulgaria. Among the studied progenies are those of the clones Pordim-6 and Obretenik-6, which show good growth in different types of habitats. When testing the vegetative progenies of 10 black locust clones Broshtilov (2003) found that progenies of the Obretenik-4 and Ryahovo-1 clones with the best productive habitat with cinnamon forest soil have the best growth.

Table 3 *Results of statistical tests for comparison of the quantitative parameters of seedlings from selected Robinia pseudoacacia L. clones*

Source of variation	Mean height of the seedlings									
	Seed rows					Containers				
	Sum of squires	Degrees of freedom	Mean Squire	*Coef.* F	Statist. significance	Sum of squires	Degrees of freedom	Mean Squire	*Coef.* F	Statist. significance
Between clones	9463.91	6.00	1577.32	37.38	<0.001	120.88	6.00	20.15	4.63	<0.001
Within clones	7089.52	168.00	42.20			730.64	168.00	4.35		
Mean diameter of root collar										
Between clones	1.15	6.00	0.19	9.69	<0.001	0.16	6.00	0.03	3.59	<0.001
Within clones	3.32	168.00	0.02			1.28	168.00	0.01		
Mean length of root										
Between clones	795.5	6.0	132.6	13.9	<0.001	45.3	6.0	7.6	10.3	<0.001
Within clones	1600.8	168.0	9.5			123.5	168.0	0.7		

* One-way analysis of variance

Of the selected black locust clones in Hungary, the Jászkiséri clone has good dendrobiometric parameters and is used to create both productions, short-rotation, biomass and energy plantations (Rédei, 2010; 2011). The half-sibs progenies of the two Bulgarian (Tsarevets and Karaisen) and one Hungarian (Roszin Varga) black locust studied in Bulgaria are characterized by good dendrobiometric characteristics, which confirm their good qualities (Dimitrova, 2019).

Despite the fact that the seeds were sown under the same condition in both variants of the experiment, the average values of seedlings height, root length and diameter of root collar differed in the progenies of black locust clones. This is a proof that the origin of the plant material, in case the seeds of different black locust clones, is of great importance for development and growth of the seedlings. On the other hand, regardless of the reproductive material, the initial height and diameter of the root collar are important for the survival and growth of seedlings in the first year (Ivetić et al., 2016).The progenies of Jaszkiseri, Appalachia and Ryahovo-7 clones have the best quantitative parameters of seedlings and can be used for the production of black locust seedlings in both of variants – seed rows and containers.

Conclusion

The assessment of the qualities of half-sibs progenies from selected *Robinia pseudoacacia* L. clones shows differences in the quantitative parameters of one-year-old seedlings. The progenies of the clones Appalachia, Jaszkiseri и Ryahovo-7 are characterized by highest height, root length and diameter of the root collar of the seedlings in two variants of the experiment – seed rows and containers.

This suggest a correlation between the seed provenance and the growth of seedlings, which are probably genetically justified. Clones Appalachia, Jaszkiseri и Riyhovo-7 are most suitable for production of black locust seedlings based on their quantitative parameters with good seed germination and established sowing rates.

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ANNIVERSARY

Academician Alexander Nikolaev Sadovski, 85 years old

Alexander Sadovski was born in Sofia on May 14, 1937. Received secondary education in the town of Lukovit, 1955. Graduated from higher education, Master's degree in Mathematics at Sofia University "St. Kliment Ohridski", 1962. He began his scientific activity in the Department of Astronomy at the Bulgarian Academy of Sciences, 1966. In 1971, he joined the N. Poushkarov Institute of Soil Science as a Research Associate First degree. He received the scientific degrees and titles of Doctor of Mathematics, 1976; Associate Professor (Senior Research Associate 2nd degree), 1978; Doctor of Agricultural Sciences, 1986; Professor (Senior Research Associate 1st degree), 1989.

In 1994, he was awarded the title of Academician (Full Member) of the International Eurasian Academy of Sciences (IEAS/EUROPE) and was elected President of the Bulgarian Science Center of IEAS, 1996. He is a Full Member of the New York Academy of Sciences, 1997.

Sadovski specializes in Computing and Mathematics at the Polish Academy of Sciences, Warsaw; Business Administration in the GDR, Berlin; Statistics at the Statistical Department of the Rothamsted Experiment Station, England and Computer Technology in Agriculture at the Salzburg Seminar, Austria. Completed courses in: Financial engineering and Risk management at Columbia University, USA; Statistics and Public Health at Johns Hopkins University, USA; Epidemiology at the University of North Carolina – Chapel Hill, USA; Fundamentals of Clinical Trials at Harvard University, USA; Planning and interpretation of Clinical Trials at Johns Hopkins University, USA; Constitutional Law at Yale University, USA.

The scientific and applied activity of Alexander Sadovski at the Institute of Soil Science "N. Poushkarov" during the period 1971-1987 was carried out during the time of the eminent scientists and heads of the Institute, Prof. Ivan Garbouchev and Assoc. Prof. Lyuben Glogov, holding the positions of Head of Department and Head of the Division "Mathematical Modeling, Software provision and Information-Computing center". His readiness for cooperation and joint scientific activity with them and other scientists from the Institute, such as professors Yordan Shanin, Miroslav Benevski and a number of others, are proof of his scientific ethics and preparation. He is one of the main members of the team of scientists who participated

in the development and implementation of the Automated System for Soil-Agrochemical servicing of Agriculture. The functioning of this system is carried out with the designed Semi-automatic line for mass agrochemical analyzes PALMA. In 1980, the System was implemented on 71,404 fields with a total area of 70,210,738 decares. It was awarded by the State Committee for Science and Technical Progress. He developed with Prof. Georgi Krafti and Prof. Iliya Christov the first computer system for irrigation forecasting and management. Sadovski creates the theoretical and experimental foundations of a new intermediate scientific field - Mathematical Agronomy as a branch of General Agriculture. The development received a positive international evaluation from Academician Ivan Shatilov, Prof. Ratmir Poluektov, Prof. John Gower and Prof. Donald Nielsen.

From 1987 to 1992 he was Deputy Director General of the Environmental Research and Information Center at the Ministry of the Environment; in the period 1992 - 2000 he was Actuary, Chief Actuary and Director at Health Insurance and Assurance AD "Zakrila". From 1995 to 2000, he was a Professor at the "St. Kliment Ohridski" University and introduced for the first time in Bulgaria a course on the discipline of Geographical Information Systems. During the period 2001 - 2008, he was an Invited Professor at universities in the USA and a Scientific Consultant for the Health Assurance Company "Blue Cross", Pennsylvania – USA.

From 2011 to 2013, Sadovski was a high-ranking representative of the academic community as a Member of the Insurance and Reinsurance Sector Group (IRSG) of the European Insurance and Occupational Pensions Supervisory Authority (EIOPA) of the European Parliament and the Council of the European Union. In 2014, he was elected as a Member of the Steering Committee of the Health Section of the International Actuarial Association. He continues to actively participate in scientific projects of the Institute of Soil Science, Agrotechnology and Plant Protection "N. Poushkarov" and passes on his experience to the young researches.

His scientific activity and practical experience are in the field of Applied Mathematics and Statistics, Agriculture and Biology, Environmental Protection, Geographical Information Systems, Non-Conventional Energy Sources, Health Assurance and Insurance. He developed a new method for self-organization of mathematical models and participated in the development of the first Bulgarian voluntary Health Assurance system. Conducts research on the potential of non-traditional energy sources in Bulgaria - solar radiation, wind energy, mineral waters and hydrogen.

Sadovski is a scientist with over 250 scientific and applied scientific publications, reports, technological projects, insurance and health assurance products, popular articles, books and an invention patent. He has participated in numerous national and international scientific congresses, conferences, seminars and sessions. He was the supervisor and reviewer of master's and doctoral theses; Lecturer at the Institute for Advanced Studies, Caracas, Venezuela; member of expert groups in Bulgaria, USSR, Austria and Greece.

He is a member of several Bulgarian and foreign scientific and professional organizations, among which: International Actuarial Association, American Statistical

Association, Society for Ecological Engineering and Environmental Protection, Union of Automation and Informatics, Bulgarian Statistical Society, Working Group on Soil Information Systems , International Union of Soil Sciences, Bulgarian Society of Soil Science, International Society of Psychometrics, International Committee for Space Research COSPAR. He is a member of the Editorial Board of the journal "Ecological Engineering and Environmental Protection" and "Open access Journal of Environmental & Soil Science", as well as a reviewer of a number of Bulgarian and foreign journals.

Alexander Sadovski was awarded the Order of “St. Cyril and Methodius”, 1st degree, Honorary Medal "1300 Years of Bulgaria", Honorary Medal of the Bulgarian Soil Science Society, Honorary Medal of the Union of Mathematicians in Bulgaria, Golden Badge "Excellent of the Committee for Environmental Protection" and has been nominated as an "Eminent Person of the 21st Century" by the International Biographical Center, Cambridge, England.

/Note: In the National Library "St. Cyril and Methodius", the Central Agricultural Library, the library of the Institute "N. Poushkarov" in Sofia and the library of the Agrarian University in Plovdiv the monographs of Academician Sadovski are deposited:

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Happy Anniversary, Acad. Sadovsky!

Prof. Metodi Teoharov
President of Bulgarian Soil Science Society

ANNOUNCEMENTS

ESDAC Newsletters

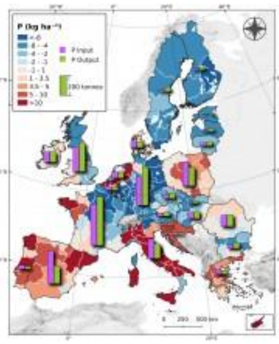
Panos Panagos
Joint Research Centre, European Soil Data Centre

ESDAC Newsletter No145 (September, 2022)

JOINT RESEARCH CENTRE
EUROPEAN SOIL DATA CENTRE (ESDAC)
European Commission

ESDAC: http://esdac.jrc.ec.europa.eu   ESDAC Newsletter No **145** (September 2022)

Phosphorus budget and P stocks



We estimate the Phosphorus (P) budget from agricultural lands of EU and UK (ca. 173 million ha). This takes into account the P inputs (fertilizers, manure, chemical weathering, atmospheric deposition) and the P outputs (crop production, plant residues removal, losses by erosion) for the period 2011–2019. The P budget and the P inputs/outputs are available at NUTS2 (Regional scale) and country scale. In addition, we estimate the P displacement and losses due to water erosion at catchment scale and aggregate them at sea outlet. We make also the datasets for both Total P and Available P (Olsen) concentration and stocks available. More details of the empirical model is given in the published study. Data available:

https://esdac.jrc.ec.europa.eu/content/phosphorus-budget-and-p-stocks

Second EUSO Stakeholders Forum, 24-26 October 2022

The 2nd EU Soil Observatory (EUSO) forum will be a 3-days event in October. The first day will deal with "Recent EU policy developments in soil". The second day will discuss the concept of Soil Health Districts, and discuss the EUSO engagement with the Mission "A Soil Deal for Europe". The third day will be dedicated to look at the work done in the EUSO Technical Working Groups. The event is virtual and open to the public; it will also be broadcasted. Interested in an account of what EUSO accomplished during its first year since its start? JRC prepared the EUSO 2021 review report. You can register your participation here: https://ec.europa.eu/eusurvey/runner/EUSOFORUM2022

Find the draft agenda of the Forum.

PREPSOIL project

PREPSOL stands for Preparing for the 'Soil Deal for Europe' Mission". This EU-funded project will support the implementation of the Soil Mission by creating awareness and knowledge on soil needs among stakeholders in regions across Europe. PREPSOIL will widen the understanding of Living Labs as a vehicle for engaging stakeholders in soil improvements in different land use types (agriculture, forestry, urban, etc.). PREPSOIL will create understanding of how different approaches to soil monitoring may support the transition to sustainable land use; it will engage with soil ambassadors and collect information on soil education by establishing a one-stop-shop for soil literacy, communication and engagement as a state-of-the-art web platform. Project website: http://www.prepsoil.eu. JRC will actively participate in all project activities ensuring effective collaboration with EUSO.

https://esdac.jrc.ec.europa.eu/projects/prepsoil

Call for costs of sediments removal

The EUSO Working group on soil erosion addresses the question on the costs of sediments removal. This WG will develop a study on estimating the off-site costs of soil erosion. Therefore, there is a call for data on the costs of removing sediments from dams, ports, rivers, etc. In case you are aware of studies or reports quantifying the costs of removing sediments (or energy revenue costs due to sedimentation), please contact the WG chair:
panos.panagos@ec.europa.eu. The overall objective is to have a pan European estimation of sediments removal. The topic will be also addressed during the WG soil erosion session on 26th October 2022.

Download the ESDAC Newsletter : PDF Format. **Feedback**: panos.panagos@ec.europa.eu

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ESDAC Newsletter No146 (October, 2022)

JOINT RESEARCH CENTRE
EUROPEAN SOIL DATA CENTRE (ESDAC)

ESDAC: http://esdac.jrc.ec.europa.eu ESDAC Newsletter No **146** (October 2022)

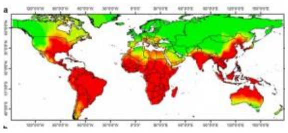
Second EUSO Stakeholders Forum, 24-26 October 2022

The 2nd EU Soil Observatory (EUSO) forum will run next week and will be a 3-days on-line event. The first day will deal with "**Recent EU policy developments in soil**" including the EU Soil Strategy, the EU Mission "A Soil Deal for Europe", Carbon Farming and Zero Pollution. We also invited high level speakers. The second day will discuss the concept of **Soil Health Districts**, and discuss the EUSO engagement w ith the Mission "**A Soil Deal for Europe**". In addition, we will present the EUSO engagement with the HORIZON (Soil Mission) upcoming projects. The third day will be dedicated to look at the work done in the EUSO **Technical Working Groups**: Monitoring, Data, Pollution, Erosion and Carbon. The event is virtual and open to the public. Interested in an account of what EUSO accomplished during its first year since its start? JRC prepared the EUSO 2021 review report. You can still register your participation here: https://ec.europa.eu/eusurvey/runner/EUSOFORUM2022

Find the latest agenda of the Forum on:

https://esdac.jrc.ec.europa.eu/euso/second-euso-stakeholders-forum

Global assessment of storm disaster-prone areas



Rainfall Erosivity Density (RED) is a measure of rainstorm aggressiveness and a proxy indicator of damaging hydrological events. By using measured Rainfall Erosivity Density (RED) for 3,625 raingauges worldwide and applying kriging methodologies, we could identify the damaging hydrological hazard-prone areas that exceed warning and alert thresholds (1.5 and 3.0 $hm^{-2}\ h^{-1}\ yr^{-1}$, respectively). In this study, we analysed the spatial pattern of hydrological hazard associated with rainfall erosivity with a global-scale visualisation. The results indicated that about 31% and 19% of the world's land area have a greater than 50% probability of exceeding the warning and alert thresholds. Data available:

https://esdac.jrc.ec.europa.eu/content/global-rainfall-erosivity

LANDSUPPORT Decision Support Systems (DSS)

This report from the EU-funder project LANDSUPPORT presents the analysis carried out concerning the LANDSUPPORT DSS's ability to support EU policies when applied at the EU scale. Key EU policies of interest include the 7th Environmental Action Programme; COM 2006/231 Soil Strategy, Dir 2000/60/EC Water Directive; Dir 2007/2/EC INSPIRE Directive. and the land-related targets of the 2030 Sustainable Development Goals (SDGs) in particular, SDGs 2

"Zero Hunger", 3 "good health and well-being", 13 "Climate action", 15, with a special emphasis to the key SDG 15.3.1, "achieving a land degradation-neutral world" (LDN) and climate change (CC) mitigation goals. Download the report:

https://esdac.jrc.ec.europa.eu/public_path/shared_folder/doc_pub/Landsupport.pdf

Land and Soil Management Award

The European Land Owners Organisation (ELO) is going to reward land use and soil management practices mitigating soil threats. You can apply for this award until 15 January 2023. The award is bestowed to the winner every year during the Forum for the Future of Agriculture.

https://www.europeanlandowners.org/awards/soil-land-award

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BULGARIAN JOURNAL OF SOIL SCIENCE®

INSTRUCTIONS FOR AUTHORS

Manuscript Submission

Submission of the manuscripts implies that they have not been published before nor are currently submitted or considered for publication in any other journals, which should be declared in **cover letter** by the authors.

The manuscripts must be submitted in electronic version to the Editorial e-mail address: Journal@bsss.bg* and *bulsoil@gmail.com

Language

Manuscripts should be written in clear and grammatically correct English. British or American English spelling and terminology must be used. If English is not your native language we strongly recommend that the text of your paper be checked by a native speaker or a professional science editor before submission.

Types of Manuscripts

Bulgarian Journal of Soil Science publishes four categories of papers and the authors must indicate the category of their submission in the cover letter:

- Regular research papers must be based on results of original research. They will normally have a maximum length of 20 pages including tables, illustrations and references (on separate sheets).
- Research notes and short communications should be concise, focused on new results and data. They will be no longer than 5 pages, including the tables and figures.
- Review papers (invited or consulted with the Editor prior to preparation of the manuscript) with maximum length of 25-30 pages (according to the importance of the material).
- Book reviews and critical comments on articles and events up to 3 printed pages.

General presentation of the manuscripts

The manuscripts should be double-spaced (1800 characters per page), without section breaks, on A4 (210 x 297 mm) paper size, with margins of at least 2.5 cm at the top, bottom and sides. Lines should be numbered in the margins with a continuous numbering from the start of the manuscript. All pages should be numbered consecutively in the bottom, right-hand corner.

The manuscript should be arranged as follows:

Title Page

The title page should include:

- Full and short (running head) titles of the manuscript. The full manuscript title must be limited up to 20 words, and the short title – up to 7 words in small capitals;
- The name(s) of the author(s) in small capitals;

- The affiliate institutions(s) and address(es) of the author(s);
- The e-mail address of the corresponding author.

Abstract

Please provide an abstract up to 1500 characters that includes a clear statement of the research objectives, a short overview of the methods used, the most important results and a conclusion. No references and abbreviations should be used in the Abstract.

Key words

Please provide 4 to 6 key words, which can be used for indexing purposes. Avoid overlaps with the title.

Order of sections

The standard order of sections should be: Introduction, Material and Methods, Results, Discussion (or Results and Discussion), Conclusion, Acknowledgements, and References.

The content of the manuscript should be structured in accordance with the following criteria

Introduction. It should present a general framework of the topic in justifying why the authors have performed the study. State-of- art on the research topic has to be presented briefly to derive the novelty of the study and to show its relation to the preceding works. A distinct paragraph at the end of this chapter should state the objectives of the work.

Materials and Methods. This chapter should present detailed information of the place of research, as well as of data collection and analyses. Sufficient detail should be provided to allow the work to be reproduced. Methods already published should not be described in text but rather indicated by a reference.

Results and Discussion. It is recommended that results of the research are presented in a clear and concise manner. Information in charts, tables, photos or graphics should not be repeated in the text. This chapter should not contain a comparative assessment with similar papers or information on data analyses procedures. Also to make a comparative analysis between the results of the current research and those already published. This should not reiterate the results of the work but rather explore their significance. Published literature which is relevant to results and aim of the current study should only be cited.

Conclusion.

This chapter or subsection of the discussion chapter should be concise and derived from the results of the research and the discussion presented. General statements are not allowed.

Scientific style

Please always use internationally accepted signs and symbols for units, SI units. Genus and species names should be in italics.

Text Formatting

- Use a normal, plain font (e.g. 12-pt Times New Roman) for text and line spacing at 1.15.
- Use italics for emphasis.
- Use the automatic page numbering function to number the pages.
- Do not use field functions.
- Use the equation editor for equations.
- Save your file in *.docx format.

- Headings. Please use no more than three levels of displayed headings.
- Abbreviations should be defined at first mention and used consistently thereafter.
- Footnotes can be used to give additional information. Footnotes to the text are numbered consecutively; those to tables should be indicated by superscript lower-case letters (or asterisks for significance values and other statistical data). Footnotes to the title or the authors of the article are not given reference symbols.
- Acknowledgments (10-point plain font) of people, grants, funds, etc. should be placed in a separate section before the reference list. The names of funding organizations should be written in full.

Tables

The tables should always be cited in text in consecutive numerical order and must be numbered using Arabic numerals. Each table must be as simple as possible, double-spaced, of size no bigger than 12 x 18 cm. For each table, please supply a table caption (title) describing its content. Footnotes to tables should be indicated by superscript lower-case letters or asterisks and included beneath the table body.

Example: **Table 1.** *Soil indexes in the territory (2015–2016).*

Illustrations

All illustrations, including charts and photos, must be labelled as Figures. They must be numbered consecutively and should be provided with an explanatory legend on a separate sheet entitled ‘Figure captions’. They should conform to the size of the typed area (12 x 18 cm) which is the maximum size for the illustrations. Magnification should be shown by scale bars. Files in XLS, TIF, JPG and WMF formats are accepted. After the paper is accepted the editors will ask for figures in JPG or TIF format with 300 Dpi. Colour illustrations are accepted without fees for electronic publications. The editors reserve the right to decide what figures are justified and can be published in RGB colour (other figures will be removed or published in black and white).

Example: **Fig. 1.** *Soil map of the study area.*

Citation and References

From July 2021, Bulgarian Journal of Soil Science adopts the APA (American Psychological Association) bibliographic style (7th edition – 2020). APA Referencing Basics: In-Text Citation.

Citation

Cite references in the text by name and year in parentheses as follows: Bauer (1932) or Bauer, Smith (1951) or (Bauer, 1930; Smith and Albert, 1931, 1935; Bauer et al., 1965) or Steffanic et al. (1951), up to two authors, give the names; for more than two authors, give the name of the first author followed by ‘et al.’. Check each reference with the original article and refer to it in the text. All authors of a paper should be cited in the list of references. References ‘in press’ shall only be cited when they have been accepted for publication.

Reference list

If the author of the cited source is unknown, the first few words of the reference should be used. This is usually the title of the source. If this is the title of a book, periodical, brochure or report, is should be italicised. For example: (IUSS- Working group, 2015). If this is the title of an article, chapter or web page, it should be in quotation marks. For example: (“APA Citation”, 2017). Citing a group or organization: (World Olympic Committee, 2018).

References should be arranged first alphabetically and then further sorted chronologically if necessary. More than one reference from the same author(s) in the same year must be identified by the letters 'a', 'b', 'c', etc., placed after the year of publication.

For example: (Hristov, 2017a) Or (Hristov, 2017b). In case of papers written in other than Latin letters, if there is an English (or German, French) title in the summary, it may be used. If there is not such a summary, the author's name must be transcribed (using British English transcription) and the title of the paper must be translated into English. This should be noted in round brackets at the end of the paragraph, for instance: (In Bulgarian).

Reference list

References should be arranged first alphabetically and then further sorted chronologically if necessary. Some examples for references to journal publications, books, chapters in edited books and electronic publications or databases:

Journal articles

- Atanassova, I., Doerr S. (2010). Organic compounds of different extractability in total solvent extracts from soils of contrasting water repellency. *European Journal of Soil Science*, 61(1),298-313.
- Calderón, H. W. (1982). The content and composition of humus in arid alluvial soil of Peru. *Soil Science, Academy of Sciences of USSR*, Moscow, 8(1), 53-59. (in Russian).

Books

- Sparks, D. L. (2002). *Environmental Soil Chemistry*, 2nd Edition, Academic Press, San Diego, CA.
- Lidanski, T. (1998). *Statistical methods in biology and agriculture*. Zemizdat, Sofia (in Bulgarian).

Book chapters or conference proceedings

- Maison, S. P. (1993). Advanced soil remediation. *In: Plants that accumulate heavy metals* (P. D. Tooks, ed.). CAB Int., Wallingwood, USA, 291-307.
- Kostov, D., Radev, H. Peeva, M. (2008). Study of newly introduced cultivars of green and red apples. *In: Sustainable Fruit Growing: From Plant to Product, Proceedings of International Scientific Conference, Bulgaria*, 46-53.
- Petrova, R. (1989). Loss of Humus Soil in the Process of Reclamation of Damaged Terrains. In: *Fourth National Conference on Soil Science 'Problems of Soil Science in Intensive Agriculture'*(N. Sherbanova, R. Nacheva, Eds.).. BSSS, N. Poushkarov Soil Science and Yield Programming Institute, Sofia, 203-206, (In Bulgarian).

Online publications

Lecoq, H. & Desbiez, C. (2012). Viruses of cucurbit crops in the Mediterranean region: an ever-changing picture. *Adv. Virus Res.*, 84, 67-126. http://doi.org/10.1016/B978-0-12-394314-9.00003-8.

Dissertations and Phylosophy Doctor Theses

Hristova, M., 2013. content and availability of microelements-metals in Technogenic soils. Ph.D. Thesis. Agricultural Academy, ISSAPP 'N. Poushkarov', Sofia, 140. (In Bulgarian) .